

ENDEAVOUR



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The drawing on the cover is of the bark Endeavour, which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in 1768 to chart the South Pacific Ocean and observe the transit of Venus.

ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

VOLUME X

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A British whimsy

Britain is an island—a geographical fact possessing both advantages and disadvantages for the islanders. The twenty-mile gap of salt water which separates Dover from Calais has proved an invincible defence for nearly a thousand years, but it may also have acted as a barrier to ideas. Insularity in itself is not necessarily a drawback, and no one could accuse Britain of paucity of inspiration, yet an island folk is prone to develop idiosyncrasies to which it is blind, however plain they may be to onlookers. We may sigh, with Robert Burns, 'O wad some Pow'r the giftie gie us To see oursels as ithers see us !'

It is probably true that one of the chief oddities of recent British culture is the attack made from time to time by classicists upon science: the uncharitableness—perhaps not all upon the one side—may lie latent for a while, but, like an epidemic disease, it flares up now and again with greater or less virulence. A recent outbreak, well ventilated in the British press, showed so little appreciation of the spirit of science that it is worth scrutiny and rebutment.

Put shortly, the argument of the classicists was that science has little, if any, educational value, and that the only valid basis of education is the study of Latin and Greek language and literature. Some of the classicists had the comfortable logic that an educated man is one who knows Latin and Greek, and that therefore Latin and Greek are essential to education—a begging-the-question surprisingly prevalent but of course usually disguised in agile verbosity.

One wonders whether the classicists fully realize the implications of their thesis. Ancient Egyptian astronomers invented the calendar; Urukagina, Gudea, and Hammurabi established comprehensive codes of law; and Hindu poets had shaped the Rigveda by 1000 B.C.—yet all these must be regarded as uneducated men inasmuch as they were ignorant of Latin and Greek. Even Shakespeare, with his 'small Latin and less Greek,' could have been at best only half educated. The thesis is, in fact, palpably absurd when considered as absolute. There is more to be said for it, however, from a relative point of view, but perhaps we may first consider why many British classicists are so intransigent in their attitude towards science.

The intransigence is not very deep-rooted; it is mainly a product of the nineteenth century. To

Newton, the idea of an inimical opposition between classical learning and science would have appeared meaningless, but signs of the approaching rift came with Joseph Priestley, who wrote 'Let it be remembered that a taste for science, pleasing, and even honourable as it is, is not one of the highest passions of our nature, that the pleasures it furnishes are even but one degree, above those of sense, and therefore that temperance is requisite in all scientific pursuits.' The learned Dr David Hartley was more severe. 'Nothing,' he says, 'can easily exceed the vain-glory, self-conceit, arrogance, emulation, and envy, that are found in the eminent professors of the sciences. . . . Temperance in these studies is, therefore, evidently required, both in order to check the rise of such ill passions, and to give room for the cultivation of other essential parts of our natures.'

The Industrial Revolution brought about a further hardening of thought. Science became more and more involved with trade, and though Victorian England was fully alive to material benefits it maintained a rigid distinction between tradesmen and gentlemen—tradesmen had even to call at a gentleman's house by a special entrance. Gentlemen educated their sons at the great public schools—'public,' in this case, by one of the inconsistencies of the English language, meaning private—and the education was almost entirely classical. Science did not begin to form a part of the curriculum until the latter half of the century, and was very slow to establish itself. 'I am afraid we now have to teach science,' a former headmaster of a well known public school is reported to have said when showing parents the new school laboratories, 'but we still manage to produce gentlemen.'

Other factors contributed to the somewhat contemptuous recognition of science, not the least of them being the repugnance aroused in pious minds by Darwin's *The Origin of Species* and *The Descent of Man*. Many worthy Englishmen sincerely felt that if science shook fundamental beliefs it should be avoided as a plague, and the repercussions of this feeling struck far and wide. There was also a curious incredulity as to the practical possibilities of scientific discovery. It is true that the great exhibition of 1851 was partly designed to display scientific achievements, but many years later the famous English statesman,

Gladstone, said to Faraday at the Royal Institution (so the story goes): 'This invention of yours is very interesting, Professor Faraday, but what is the use of it?' Faraday replied, with quiet humour, 'Sir, there is every probability that in a few years' time you will be able to tax it.' The story may not be true, but it is indicative of an attitude common in nineteenth-century Britain.

It is against such a background that we must view the British classicists' disparaging opinions of science. No one is likely to dispute the educational value of Latin and Greek, for classical culture forms so great a part of our intellectual heritage; our thought is still largely moulded by Athens and our administration by Rome. Yet the sum of human knowledge has increased immeasurably since Horace led a pleasant life at his Sabine farm and Aristotle accompanied Alexander on world conquest: it can no longer be maintained that in Plato and Sophocles, in Ovid and Virgil, the twentieth century can find all the mental sustenance it requires. 'I have taken all knowledge to be my province,' wrote Bacon to Lord Burleigh, and that surely should be the maxim for everyone who aspires to be considered educated. Classicists who know nothing of science are as imperfectly educated as scientists who know nothing of the humanities; neither should be satisfied with their enthusiasm for one particular subject, for by being so they miss the poise and graciousness of life. And, indeed, as was well said by Arthur James Balfour, 'it is unfortunate, considering that enthusiasm moves the world, that so few enthusiasts can be trusted to speak the truth'—a remark that applies as much to scientists pleading for science as to classicists pleading for the classics.

It is a fact that most of our leading British men of science have displayed an interest in, and a knowledge of, the humanities which is far from being at odds with their scientific training. Indeed, their training in science seems often to have awakened their minds to the values inherent in the legacy of Greece and Rome: is it too much to hope that our humanists may gradually come to recognize that the same values, in different aspects, exist also in the realm of science? The ecstasy of Keats in poetic creation, the 'dark passion' of Mozart, the quintessential delicacy of Botticelli, are all to be paralleled in Faraday's delight in a successful experiment, Rutherford's delineation of the structure of the atom, and Kelvin's lifelong satisfaction in the result of an acute piece of reasoning.

There is a great passage which provides the answer to the question as to what constitutes a liberal education. It runs as follows:

'That man, I think, has had a liberal education, who has been so trained in youth that his body is the ready servant of his will, and does with ease and pleasure all the work that as a mechanism it is capable of; whose intellect is a clear cold logic engine, with all its parts of equal strength, and in smooth working order; ready, like a steam engine, to be turned to any kind of work, and spin the gossamers as well as forge the anchors of the mind; whose mind is stored with a knowledge of the great and fundamental truths of nature and of the laws of her operations; one who, no stunted ascetic, is full of life and fire, but whose passions are trained to come to heel by a vigorous will, the servant of a tender conscience; who has learned to love all beauty, whether of nature or of art, to hate all vileness, and to respect others as himself.

'Such a one and no other, I conceive, has had a liberal education, for he is, as completely as a man can be, in harmony with nature. He will make the best of her, and she of him. They will get on together rarely; she as his ever-beneficent mother; he as her mouth-piece, her conscious self, her minister and interpreter.'

Can one elicit from among those who have endeavoured to define a liberal education a finer description of it than this? And the man to whom we owe the description was Thomas Henry Huxley, a leading thinker of the Victorian Age in Britain and one of its most brilliant scientists.

We should be like Bacon, and regard all knowledge as our province, neither extolling one branch nor belittling another. As scientists, we are probably far better acquainted with our shortcomings than our critics are, and many a man of science when examining aspirants has sighed at their all too frequent illiteracy. It could be well argued that in this scientific age an ignorance of letters is certainly no more deplorable than an ignorance of science, but the critics of science are essentially on a crusade for values which they know to be inestimable and fear may gradually be lost. We think that our island classicists not seldom create overseas a wrong impression of British scholarship and the attitude of British scientists towards it. The sporadic outbursts of mutual criticism are not to be taken too seriously: they are merely an example of another British whimsy.

Some results in the field of high-pressure physics

P. W. BRIDGMAN

The investigation of pressures large enough to affect the properties of materials, and now extending up to 100,000 atmospheres, is comparatively recent. It is to Professor Bridgman that we are indebted for almost all our knowledge in this new field. He here describes how such pressures are achieved, and some of the effects they cause. High pressures can create polymorphic forms of numerous substances obtainable in no other way.

In this article I shall describe some of the physical phenomena which are produced in various materials when exposed to high hydrostatic pressures. Pressure is not usually thought of as having any important effect on the properties of materials, and indeed under the ordinary conditions in which human beings live it does not. The effect of temperature is usually far more important for us, for temperature changes may produce such important results as the conversion of ordinary liquid water to solid ice or gaseous steam. One reason for the comparative unimportance of pressure is that the variations of pressure which we can easily produce are, so far as the molecules are concerned, not large. Under pressures which are large for the molecules, changes may be produced quite as drastic as those brought about by changes of temperature. For example, water may not only be frozen solid by the application of pressure alone, but pressure is capable of producing seven different kinds of ice, something which mere alteration of temperature is unable to accomplish.

The pressures which are large enough to affect molecules are in general of the order of thousands of atmospheres, and it is with such pressures that we shall be concerned here. To set the scale, a thousand atmospheres, or some 15,000 lb per square inch, is approximately the pressure at the deepest part of the ocean, produced by a column of water six miles high. Two thousand atmospheres is approximately the pressure in the explosion chamber of a large gun. From the cosmic point of view, the importance of understanding the effects of pressures of this magnitude is obvious, because all except a small fraction of 1 per cent. of the matter in the universe exists under pressures greater than 1000 atmospheres.

In extending scientific measurements into the realm of pressures of this magnitude, various tech-

nological problems are encountered. There is in the first place the problem of preventing leakage of the liquid by which pressure is transmitted. This problem may be solved by designing the packing in such a way that the pressure in it is maintained automatically, by the liquid pressure itself, at a level higher by a fixed percentage than that in the liquid. The principle will be clear from figure 1, which illustrates the packing on the end of a piston by which pressure is generated. A piston packed in this way cannot leak, so that all one needs to do to produce any desired pressure is to push the piston into the pressure vessel with the necessary force. The force driving the piston is most advantageously obtained from a hydraulic press or some other form of hydraulic intensifier.

'Any desired pressure' is, however, obviously subject to several limitations, in particular the strength of the containing vessel and of the piston. It might perhaps be thought at first that the strength of the containing vessel could be increased indefinitely, merely by making the walls of the vessel of unlimited thickness. This unfortunately is not so, for even an infinitely thick vessel has only a finite strength. The reason for this is that stress and strain are concentrated at the inner parts, so that the outer parts do not do their proportionate share in supporting the pressure. In practice, it turns out that the limit for heavy cylinders of the best heat-treated steels is about 15,000 atmospheres; this may be increased for brief operations to 20,000 or more. Still higher pressures can perhaps be achieved by shrinking hoops on to the vessel, as in a well known method of gun construction, but even with such vessels the upper limit yet reached, in some experiments by Newitt, is in the neighbourhood of 30,000 atmospheres. While the pressure vessel is reaching its limit the piston also is reaching its limit, the upper limit

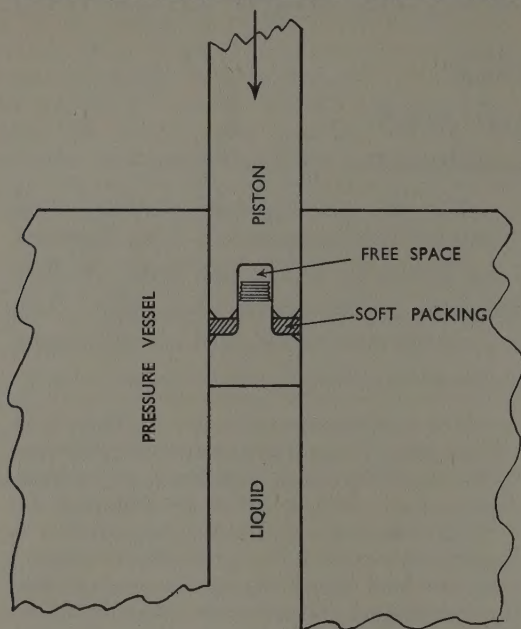


FIGURE 1—Application to a piston of the principle by which the pressure in the packing is automatically maintained at a pressure greater by a fixed percentage than the pressure in the liquid. Leaks therefore cannot occur.

for the compressive strength of any steel now available being also in the neighbourhood of 30,000 atmospheres.

To reach higher pressures, a radical change in design is necessary. For the piston, however, it is sufficient to change the material of which it is made to Carboloy, which has a compressive strength more than twice that of the best steels. Carboloy is a product of powder metallurgy, and is a sintered aggregate of tungsten carbide cemented with a small amount of cobalt as binder. To obtain greater strength in the pressure vessels more elaborate methods are necessary. In all my experiments it has involved giving the pressure vessel some sort of external support to counteract the effect of the internal pressure. The simplest way of doing this is to make the vessel conical on the outside surface and to push the entire pressure vessel into a conical supporting sleeve as internal pressure increases. The vessel may be pushed into its sleeve in various ways. The simplest is to let the thrust which drives the piston drive the vessel also into its sleeve; a method of doing this is indicated in figure 2. Alternatively, the pressure vessel may be forced into its sleeve by an independent hydraulic press coupled in the proper ratio

to the press which produces the internal pressure. The choice of method depends on the size of the apparatus, and is determined by various factors such as friction, which we cannot discuss here. The limit to the pressures which have been used in the laboratory in apparatus constructed with conical external support has been about 50,000 atmospheres. At this pressure a new limiting effect appears: this is the incipient extrusion of the pressure vessel through the supporting sleeve by the thrust, or some other sort of fracture of the vessel due to the thrust.

To reach yet higher pressures, the vessel must receive still more effective support. This may be given by immersing the pressure vessel in a liquid which is itself exposed to high hydrostatic pressure. In this way the pressure vessel receives complete support over its entire external surface. This proves effective enough to extend the range from 50,000 to 100,000 atmospheres. The external supporting pressure necessary for this extension may be between 25,000 and 30,000 atmospheres.

So large an extension of range, from 50,000 to 100,000 atmospheres, by a supporting pressure of only 25,000 atmospheres, would not be possible if it were not for the change in the properties of steel and Carboloy produced by a pressure of 25,000 atmospheres. Under this pressure, steel becomes much more ductile and also stronger. Carboloy becomes stronger in compression and loses its brittleness, so that Carboloy pistons can be subjected to pressures of 100,000 atmospheres or even more. Carboloy also increases in tensile strength, so that the pressure vessel itself may be constructed

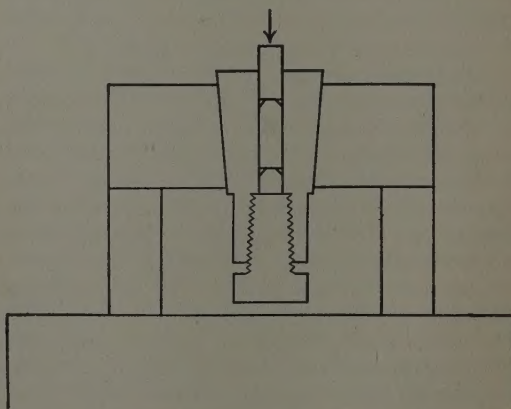


FIGURE 2—Simple method of giving external support to a pressure vessel by using the thrust on the piston which produces internal pressure to push the whole vessel into a supporting conical sleeve.

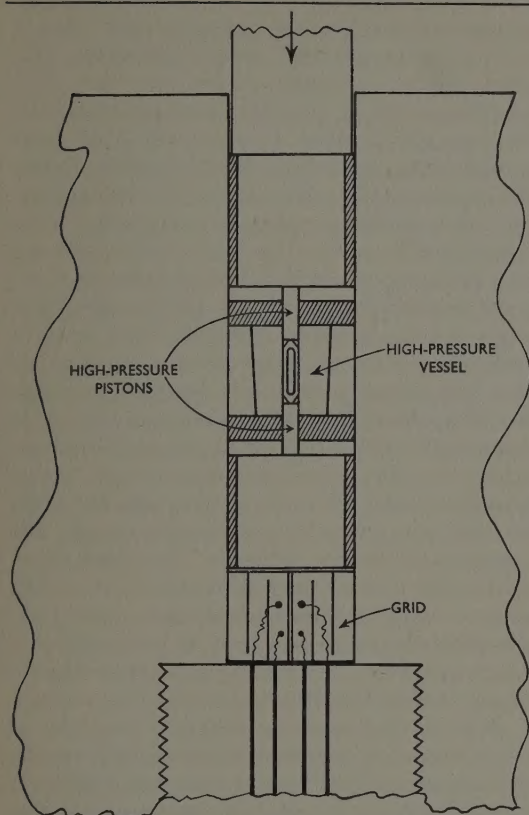


FIGURE 3 - Diagram of apparatus by which pressures of 100,000 atmospheres can be realized. The high-pressure vessel is completely immersed in a liquid (shaded) which is itself subjected to pressure and thus supports it. The thrust on the high-pressure pistons is determined by measuring the change of electrical resistance of the 'grid' which receives the thrust.

of this material, supported on the outside by a shrunk-on steel jacket. The apparatus is indicated schematically in figure 3; it is in fact an arrangement of one pressure vessel inside another. Theoretically, any extension whatever of the pressure range would be possible by this method, by making a nest of pressure vessels, each one containing a successively higher pressure supporting the vessels within. Although theoretically possible, no feasible method of constructing more than the first apparatus in such a series has been found.

It may appear paradoxical that at these very high pressures the problem which at first restricted experiments, namely the problem of preventing leak of the pressure-transmitting medium, has entirely disappeared. The reason for this is that at these pressures fluids no longer exist; all normal liquids or gases are frozen solid by the pressure. All the elements ordinarily gaseous, except helium,

have been solidified at 50,000 atmospheres, and there is good reason to think that at 100,000 atmospheres helium too freezes solid. In this region, pressures have to be transmitted by soft solids and can be only approximately hydrostatic. Fortunately there are soft solids, such as tin or preferably indium, of which the plastic shearing strength is low, so that pressure fails to be hydrostatic by only a few per cent. It is, however, not so easy to find a solid insulator which is sufficiently yielding at 100,000 atmospheres to be also a good pressure transmitter.

For every successive increase in the pressure range a price has to be paid in a diminution in the size of apparatus, which in turn limits the sort of experiment that can be made. The vessel in which a pressure of 100,000 atmospheres is generated is, on the inside, only 1.6 mm in diameter and 1.8 mm long. In this apparatus, volume changes can be measured with fair precision, and the volume changes of a large number of substances have been determined. Still higher pressures can be reached, but, at this stage, on a scale so small that little research of scientific value has been done. The principle by which these higher pressures may be reached is that used in making hardness measurements by pressing a Brinell ball or a diamond cone into the material being tested. Stresses very much higher than normal may be supported over small areas if the surrounding material is unstressed and so can support the highly stressed region. With an arrangement of this sort, in which a short Carboloy cone is pressed against a flat Carboloy block, the whole combination being mounted within a chamber at 30,000 atmospheres so that there is additional support by hydrostatic pressure, pressures in excess of 400,000 atmospheres have been realized at the point of contact of the cone. However, not much use can be made of these very high pressures, except to achieve the negative result of showing that certain transformations that might perhaps be expected are not in fact produced. In particular, graphite is not transformed into diamond by such a pressure at room temperature, although it is the thermodynamically stable form.

All the pressures mentioned so far have been static pressures. Dynamically, as in the explosion of shaped charges, it is possible to reach very much higher pressures, measured in millions of atmospheres. This is doubtless the ultimate method of getting high pressures (except by use of atomic bombs), and a beginning is now being made. The difficulties, however, to say nothing of the expense,

are immense, and progress will probably be slow. The problem of measuring the pressures and temperatures reached by such methods is itself an exceedingly formidable one, and for the present the only method seems to be to extrapolate results obtained by static methods in lower ranges. Thus the results that can be obtained by the static methods outlined above will probably continue to have their usefulness for some considerable time.

Having now discussed the various methods of achieving high pressures we may turn to a consideration of some of the effects produced. The simplest of these effects, although by no means the simplest to measure, is the diminution of volume which all substances suffer under pressure. A general feature of the volume-changes produced by hydrostatic pressure is that they are reversible, so that when pressure is released the volume recovers its original value. In other words, there is no elastic limit or fracture point. This is strikingly different from what happens when change of shape is produced by the application of powerful forces other than hydrostatic pressure. Most apparent exceptions can be explained by the closing of flaws in the materials. There are some other apparent exceptions, due to a phase of greater thermodynamic stability than the original being produced by pressure. In such cases, however, the new phase created shows no permanent change when pressure is again applied and released. The reason for the failure of hydrostatic pressure to produce permanent changes is to be sought in the atomic constitution of matter. The specific volume of a substance depends only on the nature of the atoms (or molecules) of which it is composed; neglecting isotopes, there is only one kind of iron atom, for example, not one kind before it has been compressed and another kind afterwards. This suggests that if pressures could be applied which were high enough to change the atoms themselves we might expect permanent changes of volume. Ordinarily, however, atomic transmutation is not brought about by pressure only, and we therefore have perfect volume elasticity.

In the realm of terrestrial pressures, within which the atoms remain unaltered, at least three classes of effect must be considered. In the first place there is the gaseous range. Here compressibilities are very high, volume being approximately inversely proportional to pressure. The mechanism is a kinetic one, pressure being exerted by the collision of the molecules with the walls of the container. Pressure is twice as high at half the

volume because there are approximately twice as many collisions per unit area of the walls. This effect cannot, however, persist over any considerable range of pressure, because eventually the molecules begin to interfere with each other through being pushed too closely together. When this happens a new effect occurs. Increasing pressure now pushes the molecules progressively more closely together until all the empty spaces between them are squeezed out and the molecules are effectively in contact. This is the sort of thing that occurs in the compression of liquids under ordinary conditions, or in the compression of gases under such high pressures that their density approaches that of liquids. This effect is characterized by a compressibility that falls off rapidly with decreasing volume, for at first the empty spaces can be squeezed smaller with comparative ease, but when the molecules are nearly in complete contact this possibility is greatly reduced. The third effect now begins, namely the deformation of the molecules or atoms themselves after they have been squeezed into effective contact. It is with this that we are primarily concerned in the compression of solids. Modern knowledge of the atom as a system of electrons and nucleus, depicting the atom as consisting almost entirely of empty space pervaded by an intense field of force, makes comprehensible a high degree of deformability under pressure in the atom itself. According to this picture, atoms with the most complicated electronic structures should be capable of a higher degree of compression than those with less complicated structures. This is exactly what is found. For example, nitrogen, in the region in which interference between the molecules begins and the ideal gas laws lose their validity, loses its compressibility much more rapidly than does helium, because the molecules of nitrogen are larger and are more quickly brought into contact. At still higher pressures, however, when the vacant spaces between molecules have been largely squeezed out, nitrogen becomes more compressible than helium, because the molecule of nitrogen is larger and more complex than that of helium, and therefore possesses the possibility of undergoing a greater degree of compression.

It is, of course, to be understood that there is no sharp dividing line between these three mechanisms by which a substance responds to an external pressure by losing volume; at any instant all three mechanisms are present together. It is the relative importance of the three mechanisms which changes with increasing pressure. It has

already been suggested that at still higher pressures the atoms themselves may begin to break. As a result of its complex structure an atom may conceivably break in many ways. It is quite possible that what happens may not be anything like as catastrophic and irreversible as the change we ordinarily associate with breaking; it may merely be a rearrangement of the electrons in their orbits, and there is no reason why such a rearrangement should not be reversible. At pressures higher than those yet reached in the laboratory, amounting perhaps to several millions of atmospheres, we may expect all sorts of detailed changes of this kind to be produced in atoms. In the laboratory, two instances have already been found of an inner rearrangement presumably due to pressure. The element caesium, which is the most compressible of the metals, undergoes an abrupt change of volume at 45,000 atmospheres. This change is large—17 per cent.—and there seems to be no explanation for it in terms of the ordinary lattice structure of the metal, because it is highly probable that below 45,000 atmospheres the lattice is already in the close-packed, face-centred cubic arrangement. It would seem that pressure could not make a more closely packed arrangement than one which is already close-packed. The explanation seems to be that a rearrangement of the electronic orbits within the atoms is brought about by pressure. The details have been worked out in a recent paper by Sternheimer; he shows that an electronic transition from a $6s$ zone to a $5d$ zone exactly accounts for all the experimental facts. Metallic cerium is doubtless a similar case; it shows an abrupt volume-change at 7,000 atmospheres, of the same order of magnitude as that which occurs in caesium. In the case of cerium it has been shown by ingenious experiments at the University of Chicago that both above and below the discontinuity the lattice arrangement is the same, face-centred, close-packed arrangement. The presumption is therefore again that there must be an inner electronic change, although the theoretical details have not yet been worked out.

In figure 4 the volume-changes of some of the ordinary solid elements are shown as a function of pressure in the range up to 100,000 atmospheres. There is a great variability in compressibility. The most compressible element shown in the diagram is caesium, which at 100,000 atmospheres is compressed to 37 per cent. of its initial volume. The least compressible substance is probably carbon in the form of diamond, which under the same pressure is compressed only to 98.2 per cent. of its

initial volume. The diagram indicates that for most substances the loss of volume is far from being linearly related to the pressure; the lines are strongly curved, showing that the compressibility drops off with increasing pressure. This is the same effect as we noted for liquids, but it is on a different and much more extensive scale. It must mean that inside the atom there is some sort of mutual interference between the electronic orbits, analogous to the interference between atoms or molecules which occurs in liquids. The necessity for the non-linearity in the relation between pressure and volume is obvious, for, if it were not so, volumes would eventually become negative at sufficiently high pressure. Thus it can be calculated that if the compressibility of caesium continued at its initial rate, the metal would be squeezed out of existence altogether by a pressure of only 14,000 atmospheres.

Although every volume-pressure curve must eventually be convex toward the pressure axis, there may be an opposite curvature over considerable pressure ranges. There is no mechanical or thermodynamical reason why compressibility should not in some circumstances increase with increasing pressure. Examples of this are in fact known; the most striking is perhaps quartz glass. Its compressibility increases with pressure over a wide range. Such behaviour cannot, however, continue indefinitely, and sooner or later there must be a reversal. Experiment shows that the reversal occurs at a pressure of 35,000 atmospheres, where the volume is still far above zero, being in fact 89.3 per cent. of its initial value. Above 35,000 compressibility decreases in the normal way with rising pressure. The abnormality ceases so abruptly at 35,000 that there is a cusp on the pressure-volume curve. It is as if there were some special mechanism responsible for the abnormality, which abruptly goes out of action at 35,000 atmospheres. A plausible mechanism would assume something in the nature of lenticular cavities in the structure, which are squeezed flat at 35,000 atmospheres.

The pressure-volume curves in figure 4 contain several examples of discontinuities. These are due to transitions of one kind or another. In most cases they are ordinary polymorphic transitions resulting from a change in the crystal lattice. The proof that they represent transitions of this sort is usually indirect and presumptive, but in some instances direct proof can be given. One method is by X-ray analysis of the new phase while it is under pressure. Another is to follow the transition

to atmospheric pressure by suitably changing the temperature, and then to establish the nature of the transition at atmospheric pressure by some convenient method not subject to the limitations of high-pressure measurements.

It will be seen from figure 4 that in some cases a substance may show more than one discontinuity. One of the most interesting of such substances is bismuth. At atmospheric pressure, bismuth is abnormal in many ways; in particular it is one of the few substances which, like water, expand when they freeze. Thermodynamics demands that for substances of this sort the effect of pressure should be to lower the melting-point. This effect was found for water comparatively early; the agreement between the experimentally determined and the theoretically calculated lowering of the freezing-point was in fact one of the early triumphs of the then young science of thermodynamics. Much later, I found that the melting-point of bismuth is similarly lowered by application of pressure, as would be expected. What, it may be asked, can we expect to be the ultimate course of the freezing-curve of water as we raise pressure indefinitely? In the case of water, it is found experimentally that, at first, increasing pressure only accentuates the effect, for at higher pressures the abnormal increase of volume on freezing becomes larger, and therefore the melting-point is depressed at a continually accelerating rate. One would expect that this could not continue indefinitely, and in fact it does not. It was Tammann who first found how water extricates itself from its dilemma. At -22°C and 2200 atmospheres ordinary ice abruptly gives up the unequal struggle and collapses into a new kind of ice, a very large decrease of volume occurring at the same time. In fact, the decrease of volume is so large that the new solid has a smaller volume than the liquid from which it freezes. This means that the melting-point of the new form of ice increases with rising pressure. Not only this, but, as the pressure continues to rise, the new ice discovered by Tammann eventually becomes unstable in its turn and is replaced by a succession of others, with still smaller volumes and more rapidly rising melting-points. In all, seven kinds of ice have so far been discovered. The last of these may be heated without melting to the temperature of melting solder, provided a pressure of 45,000 atmospheres is applied.

By analogy, it was expected that a new kind of bismuth would appear at high pressures to replace the ordinary abnormal bismuth, and that the

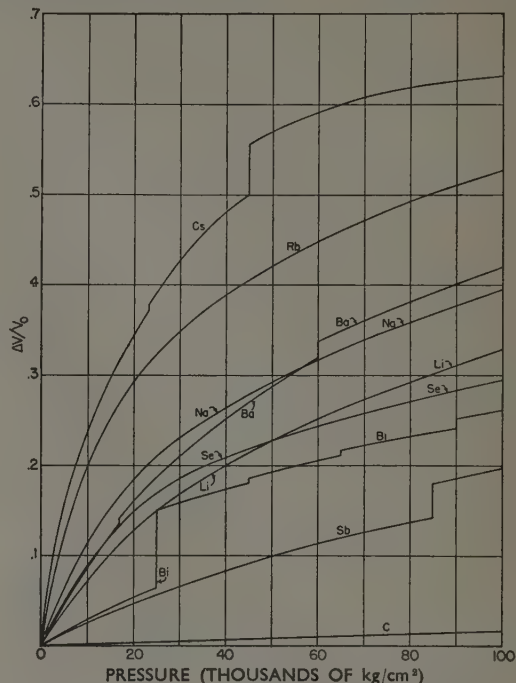


FIGURE 4—The change of relative volume of a number of substances shown as a function of pressure up to 100,000 kg/cm^2 (metric atmospheres).

melting-point of the new bismuth would rise with pressure. Search for this hypothetical bismuth was diligently made by workers in the high-pressure field, but for a long time with no success. Eventually the new modification was found, but at a pressure considerably higher than had been anticipated, namely at 25,000 atmospheres, more than ten times the pressure which produces the analogous transition in ice. Furthermore, there are still other transitions of bismuth at even higher pressures, as there are for ice. Figure 4 shows transitions at 45,000, 65,000 and 90,000 atmospheres, in addition to the one already mentioned at 25,000 atmospheres. In reality, the transition at 25,000 is double, there being two transitions so close together—within a thousand atmospheres of each other—that it would have been confusing to try to separate them in the diagram. Thus altogether there are five known transitions of bismuth, or six polymorphic modifications of the solid. This is the same as the known number of stable modifications of ice, so that the two substances would seem to be quite closely parallel.

There are two other fairly well-known elements

which, like bismuth, are abnormal in that they expand on freezing. These are antimony and gallium. The same question arises with respect to them: will they also have other modifications under pressure, and will the melting-point curve of the new modification rise instead of fall? Of these two substances antimony is in many respects much like bismuth: chemically it is closely related, and it crystallizes in the same system. Figure 4 shows that it, too, has a transition under pressure but at a pressure more than three times that of bismuth—85,000 atmospheres instead of 25,000. It may well be, therefore, that bismuth and antimony are analogous in their polymorphic behaviour. Proof of this must, however, wait until higher pressures can be commanded in the laboratory, for it would appear that the pressure scale of the phenomena in antimony is more than three times as great as the scale for bismuth. Also the melting-point of antimony is much higher than that of bismuth, so that it has not been possible to find experimentally whether the melting-point of the new antimony is raised by pressure.

The other abnormal element, gallium, proves to fall into line as well, and here the pressure scale is fortunately smaller. A new gallium appears at a pressure of about 12,000 atmospheres, and the melting-point rises with pressure. Gallium and water are parallel in that gallium has a high-pressure modification which is totally unstable thermodynamically with respect to the other modifications; similarly there is a totally unstable form of ice that appears at temperatures below 0°C and at pressures above 4000 atmospheres.

Considering all three substances—water, bismuth, and gallium—it would thus appear that pressure ultimately wipes out the ordinary abnormal forms and they become normal, at least to the extent that their melting-point rises with increasing pressure.

Figure 4 shows another example of polymorphism induced by pressure; barium possesses two transitions and three modifications. Polymorphism is indeed a phenomenon commonly encountered in high-pressure research. Among the several hundred substances that I have examined, about one-third show polymorphic transitions. The phase diagrams of most of these substances have been examined, and it is possible to show how the pressure at which a transition occurs changes with temperature. Study of these phase diagrams reveals that many of the modifications found under pressure are quite new, in that they do not occur at atmospheric pressure at any

temperature. Furthermore, there seems to be no tendency for the phenomenon to exhaust itself as the pressure range is increased; on a statistical basis, the probability that pressure will produce a new modification in an unknown substance is proportional to the pressure. The significance of this in geophysics is obvious; it means that the probability is that the materials in the earth's crust occur there in forms with which we are not familiar in the laboratory, and therefore have unfamiliar physical properties. This implies that it is hazardous to infer the composition of the earth's crust from such evidence about its properties as is given by the velocity of propagation of seismic disturbances. Uncertainty with regard to inferences of this sort can be removed only by specific and detailed knowledge.

The transitions discussed thus far have been characterized by thermodynamic reversibility; when the pressure is removed the substance reverts to its original condition, unless by chance it is hindered at comparatively low temperatures by internal viscosity. In addition to these reversible transitions there are a few examples known of essentially irreversible transitions produced by pressure. Here the substance is converted into a new form by the application of pressure; this new form is then permanently retained and is thermodynamically stable when the pressure is removed. The transformation of yellow phosphorus into black by a pressure of 12,000 atmospheres at 200°C is an example which has been known for a long time. The same transition may be made to occur at room temperature by 30,000 or 40,000 atmospheres. At still higher pressures—60,000 atmospheres or so—the more stable red or violet phosphorus may be transformed into the same black variety. Another example is carbon disulphide. This substance, ordinarily a highly volatile liquid, is slowly transformed at 175°C and 40,000 atmospheres into a permanent black solid, denser than the elements from which it is constructed.

The theory of these irreversible transitions is even less well understood than that of the reversible polymorphic transitions, and indeed, as far as I know, no example has ever been worked out theoretically. Until we have some theoretical basis for knowing what to expect, we must contemplate the possibility that any of the materials of daily life can, by sufficient pressure, be pushed over a potential hill into some entirely unknown form possessing new, and perhaps desirable, properties.

The Oxford Botanic Garden

T. G. B. OSBORN

'Amongst the several famous structures and curiosities wherewith the flourishing University of Oxford is enriched, that of the Public Physic Garden deserves not the least place, being a matter of great use and ornament.' So wrote Thomas Baskerville towards the close of the seventeenth century in his *Account of Oxford*. The Garden is the oldest of its kind in Britain.

The Oxford Botanic Garden was founded in 1621 by Henry, Lord Danvers, later Earl of Danby. He, 'being minded to become a benefactor of the University, thought that his money could not be better laid out than . . . by the foundation of a Physic Garden.' In the sixteenth century several such gardens had been established on the continent of Europe, but there was at that time none in Britain. The Oxford Garden is thus the oldest in the British Isles, and its historic interest is enhanced by the fact that it is still on the original site and enclosed by the original, magnificently gated, walls erected by the munificence of the founder. The site chosen by him was a piece of riverside meadow about five acres in extent, opposite Magdalen College and just outside the East Gate of the city. The area had been used as a burial ground by the Jews of Oxford until their expulsion in 1290. It came into the possession of Magdalen on the foundation of the college in 1458. In 1621 it was held on lease from the college. Lord Danby provided the funds necessary to buy out the sitting tenant and to transfer the lease to the university, which, in respect of this piece of land, has been a tenant of Magdalen ever since.

On the afternoon of St James's Day (25th July), 1621, there was an opening ceremony marked by speeches and the laying of a foundation stone. Thereafter the real work of forming the Garden began. The 'stately free-stone wall' was more than ten years in building. The principal gate, built by Nicholas Stone, bears the date 1632. Fully as important as the enclosure of the Garden must have been the work of raising the level of the ground above the flood-level of the River Cherwell, which forms the eastern boundary. Even today, in times of exceptional floods, pools of water may seep up inside the walls, while portions of the outlying parts may be submerged to a foot or more.

The walled Garden is rectangular, with sides 134 and 117 yards long, enclosing an area of about

3½ acres. Its first layout, as shown by Loggan's plan (1675), shows it to have been subdivided internally into quarters by hedges, inside which were flower beds arranged according to a geometrical pattern (figure 9). From the first catalogue, published in 1648, we know that more than 1600 different kinds of plants were then in cultivation. Some 600 of these were British and there were also many Canadian, but numerous others were merely varieties and sports. Nevertheless, the bringing together of such a collection within ten years represents much work.

It appears that Lord Danby intended that his foundation should provide for both a professor and a gardener. This arrangement was not completed in his lifetime. He died in 1644, leaving a small endowment for the Garden and having appointed Jacob Bobart, Senior, as gardener in 1641. The terms of the appointment are interesting. Bobart and his heirs were appointed for ninety-nine years, with a salary of £40 for labour and expenses, together with any benefits of produce. This last provision proved most important, for the salary was not paid during the troubled times of the Protectorate and Restoration. There is in the archives of the university a signed, though undated, petition from Bobart's son—also Jacob—to the Vice-Chancellor asking that he may receive a salary, and continuing: 'it is but a melancholy consideration to look back and think (and indeed as great a Wonder) that this should be the only Publick Garden of Europe that hitherto maintained itself.' Bobart refers to the indignity of having to make the market cross at Carfax 'shine with the spoils of the Garden.' No doubt the shilling which Samuel Pepys records against his visit to the Garden on 9th June, 1668, went towards the upkeep, and we may be sure that the 'very good fruit' which John Evelyn and his ladies sampled on 12th July, 1654, was not accepted without some return. In spite of all these difficulties, the Bobarts were cultivating 'exoticks' as well. Evelyn



FIGURE 1 – The western range of buildings facing the Garden, based upon one of the two orangeries built about 1730. At present they are the main laboratories of the Department of Botany. To the left is one of the Order Beds containing Labiates. The tree on the left is a swamp cypress (*Taxodium distichum*) planted about 1840.



FIGURE 2 – The eastern range of buildings, with Magdalen Tower behind. The ground floor of this building (at present the library) is the second of the two orangeries erected about 1730. The foliage in the foreground is part of the large service tree (*Sorbus domestica*).

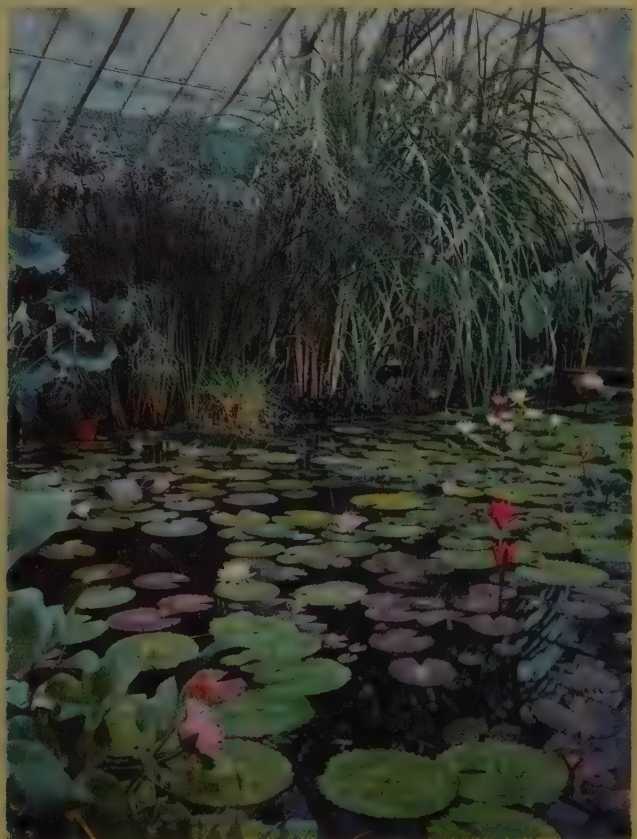


FIGURE 3 – Portion of the tropical water-lily house. In the background are plants of (left to right) lotus (*Nelumbium speciosum*), papyrus (*Cyperus papyrus*), and sugar cane (*Saccharum officinarum*).



FIGURE 4 – View outside the walled Garden looking towards Christ Church and Merton College. The left middle distance shows part of the new shrub garden. In front is the collection of hybrid irises.



FIGURE 5 – Portion of the swamp in the shrub garden. Behind, to the left, are some of the collection of species roses and cotoneasters.

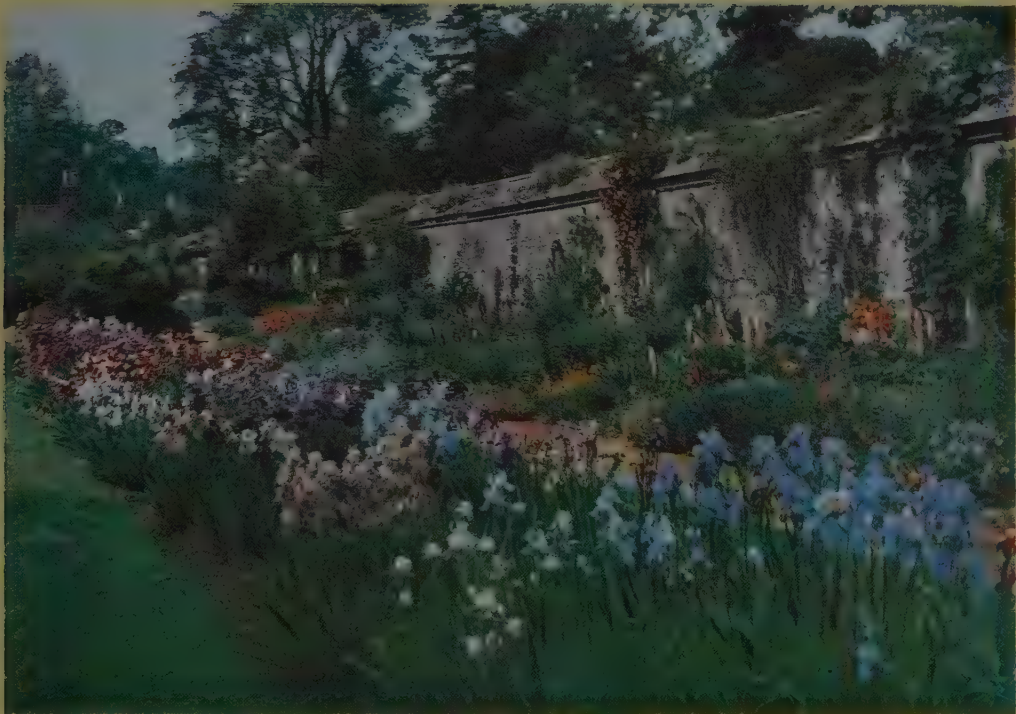


FIGURE 6 - The south-eastern wall from outside the Garden, showing the hybrid irises and, beyond the path, a mixed herbaceous border.



FIGURE 7 - View of the western portion of the walled Garden, showing the rectangular Order Beds. The large Ginkgo biloba is seen left of centre. Outside to the right is part of Merton College New Buildings, with Christ Church beyond.



FIGURE 8 – The range of greenhouses flanking the Danby Gate, from a print of 1773. The large range of buildings behind the Danby Gate formed the professor's house and library. The greenhouse on the extreme right is the present library (figure 2).



FIGURE 9 – Loggan's plan of the Garden, 1675, showing the layout in quarters separated by hedges. In the corners of the plan are elevations of the gateways and (top right) the conservatory.

records that among other things he was shown the sensitive plant *Mimosa pudica*, which also impressed Celia Fiennes on her visit some thirty years later. She records it as being a 'nice plant' and kept under glass, the air being too rough.

The first greenhouse, which was of the room or orangery type, was built outside the wall backing on to High Street, as Loggan's plan shows. It must have been very inadequate, and early in the eighteenth century the range of plant houses shown in a print of 1773 was erected (figure 8). They are referred to in a letter to Dr Richardson dated 11th July, 1734, as being built. The two greenhouses of orangery type still exist. One, in its unaltered shape, is the library (figure 2); the other has been incorporated into the laboratories (figure 1), but the piers of the doorway and two flanking windows are clearly visible in stone older than is used in the remainder of the building.

Among the manuscripts in the library is part of a notebook, probably in the handwriting of Humphrey Sibthorp, the second Sherardian professor, which gives a catalogue of the plants growing in the Garden, then evidently still divided into quarters. The last entry, which helps to date the book, is a note that a vine from Virginia had been planted in 1770. There is no evidence that any of these actual plants survive today, but it is interesting to note that some of the wall plants located in this old list have modern representatives growing in approximately the same positions, notably the honeysuckles (*Lonicera*) grown on the north face of the southern wall.

Before the close of the eighteenth century there was a drastic rearrangement, and the old traditional quarters disappeared. Arboreta, with a geographical grouping of the trees, were planted on both sides of the main north-south path, and by the eastern and western walls. It is possible that some of these trees survive: there is certainly a suggestive grouping of British, European, North American, and Asiatic trees beside these paths today. The space between the rows of trees was laid out in long rectangular beds in which the plants were arranged according to the Linnean system. During the Victorian period these were replaced by various rounded and curved beds distributed over lawns, but the Linnean system was continued over the greater part of the area. Finally, in 1886, the present layout, with rows of beds planted with herbaceous species grouped in families arranged according to Bentham and Hooker's Natural System, was adopted. Apart from its convenience to botanical

students, the regularity of these beds is in keeping with the formality of the walled Garden (figure 7). The systematical grouping is broken in front of the buildings (figure 1), and round the walls, where there is a mixture of herbaceous perennials backed by shrubs and climbing plants, placed with due regard to their need for direct sunshine or protection. A sufficient number of trees and shrubs has been left to break what would otherwise be an open expanse.

Of the trees growing within the Oxford Garden the most noteworthy is a huge specimen of *Sophora japonica*, planted about 1817 and now almost 17 ft in girth at breast height. Also remarkable is a magnificent specimen of the service tree (*Sorbus domestica*), traditionally a descendant of the famous specimen in Wyre Forest, brought to the Garden by John Sibthorp (Professor 1784-96). The tree is certainly an old one—it is 6 ft 10 in. in girth—and from its position in relation to the paths it must have been planted long before the existing layout. Its leaves, which turn a brilliant red in the autumn, are seen in the foreground of figure 2. The ginkgo is also a large one for Britain, being 7 ft 5 in. in girth. It is quite possible that this tree also dates from the late eighteenth-century plantings; it is on the Asiatic side, and Daubeney in his guide of 1853 refers to it as among the older trees.

The modern range of greenhouses dates from the last century, but the structures have been recently renewed. They are outside the walled garden, with a south-eastern aspect facing the River Cherwell. There are nine houses in all, of which seven are open to the public. A representative selection of plants is maintained, but the houses are too small to allow of any spectacular display or great specialization. The succulent collection is good, but it is no longer possible to claim—as was done in 1876—that it is second to none in Britain. Outstanding among the collections is the large tank for tropical water-lilies. Originally built for the culture of the *Victoria regia*, this was soon given up and replaced by a mixed collection of hothouse aquatics. The tank is banked by a long swamp in which, among other things, are large clumps of papyrus and sugar cane, descendants of plants which have been cultivated in this position for the last century (figure 3).

Within the last five years, the Garden has extended to the south, allowing of the development of a shrub garden. Previously, the shrubs had been crowded into shrubberies within the wall. The new ground permits the cultivation of a more

extended range, which can be grouped in related genera, while the individual plants have room to spread, so that they flower more freely. The collection of *Berberis*, though necessarily small, has been carefully selected with the aid of the Rev. Dr Ahrendt, an authority on the genus. A collection of species rose is being built up, and a number of old-fashioned roses now passing out of cultivation are preserved. Unfortunately, the heavy calcareous nature of the soil prevents any attempt to cultivate a great many popular and beautiful genera of lime-intolerant plants.

The rock garden is small, but contains a surprising number of species. Though at its best in the early part of the year, it is seldom without some object of interest to the student and to the rock garden enthusiast, though here again the growth of calcifuge species is precluded because of the limy soil and water supply.

The mass cultivation of popular species in all their range of horticultural varieties is neither possible nor desirable in a small scientific garden. An exception is made with regard to irises and roses. As can be seen from figures 4 and 6, the irises make a brave show in May and early June, soon to be followed by the roses throughout the remainder of the summer. Of late years, it has been the policy of the curators to grow groups of the more recent roses, so that visitors may judge their performance under local conditions.

It is only to be expected that, during its long history, many names famous in botany and horticulture should be associated with the Garden. The first *Horti Custos*, Jacob Bobart, Senior, was a well-known Oxford character in his day. He wore a great beard which he 'tagged with silver' on feast days, and was renowned for his topiary work, notably for two giants formed from clipped yews which, standing just inside the Danby gate on either side of the main path, appeared as guardians of the treasures beyond. Their position is indicated on Loggan's plan (figure 9).

Bobart's son was gardener when Robert Morison, appointed by Charles II in 1669 as first professor of botany in Oxford, died in 1683. Morison was engaged on a great work, *Plantarum Historiae Universalis Oxoniensis*, of which only volume II had appeared when he died. Bobart completed volume III from the material that Morison left, but volume I was never written. Bobart is mentioned several times in the works of John Ray, and is memorable because of certain observations which he made upon the possible occurrence of sexual reproduction in plants, then not recognized. Had he

published these observations at that time he might have gone some way towards anticipating the work of Camararius (1694). He held office until 1719, when he was retired in his seventy-ninth year and died shortly after.

The state of neglect into which the Garden had fallen early in the eighteenth century as a result of Bobart's old age, lack of money, and little interest on the part of the two professors who succeeded Morison (we know little of them but their names), led indirectly to a vigorous revival.

William Sherard, whose interest in botany may well owe something to Morison, for he was elected to a fellowship at St John's in the year Morison died, finally returned to live in England in 1721, after many years as Consul at Smyrna. He had collected a large herbarium and a remarkably fine library, which, together with an endowment for the chair of botany, he offered to the university if, for its part, the university would have the Garden put in order, erect proper greenhouses, and provide a regular income for maintenance. Sherard also stipulated that his botanical assistant, J. J. Dillenius, one of the foremost botanists of the day, should be the first Sherardian professor. Sherard died in 1728, and the protracted negotiations between his executors and the university afford an interesting sidelight upon early eighteenth century Oxford. In the end, Dillenius was appointed to the chair in 1734, and the university contracted to provide £150 per annum for the upkeep of the Garden. The financial arrangements were put into the hands of a committee, who drew up rules for the guidance of the professor and of the gardener. The latter was appointed by the committee, who renewed the appointment annually, a condition being that the gardener took an oath of obedience to the professor. The early minute-books show that the committee's work was not more onerous than an annual meeting, at which the accounts were received and the gardener's re-appointment was considered. The accounts for 1734 show that almost £2700 had been spent on the Garden in the previous four years.

It was early in Dillenius' tenure of the chair that Linnaeus visited the Garden. Writing to Richardson, 25th August 1736, Dillenius adds as a postscript 'A new botanist is arose in the north; a founder of a new method *a staminibus et pistillis*, whose name is Linnaeus . . . am afraid his method won't hold.' This reference, written some months after the visit, suggests that the older man still felt somewhat unkindly disposed towards the young Swede. It is said that Linnaeus' brilliant

diagnosis of the little ivy-leaved toadflax (*Linaria cymbalaria*) which still grows freely on the Garden wall, first showed Dillenius that his visitor could do more than 'bring confusion into Botany.' It is certain that Linnaeus was able to return to Holland with many plants and cuttings from the Oxford Garden desired by his patron, Clifford, which he had been unsuccessful in obtaining from the Physic Garden at Chelsea. Dillenius' letters show that he sent packets of seed to Linnaeus, on one occasion as many as 140 at one time. Dillenius was succeeded by Dr Humphrey Sibthorp, of whom it is recorded that he gave one unsuccessful lecture in the course of the 37 years that he was professor. The Garden minutes record a series of appointments of gardeners notable only for the name of G. D. Ehret, the celebrated painter of flowers. He was appointed in November 1750 at a salary of £50 per annum, with perquisites, but had to find the necessary labour. The following year he was re-appointed, but as he then refused to take the oath of obedience to the professor, the election was declared void. No doubt it is true that he had 'more ardour than the Professor' but the committee could hardly do otherwise than dismiss him.

Throughout the latter half of the eighteenth century and well into the nineteenth, the duties of the chair and the affairs of the Garden were closely interwoven. It is highly probable that the rearrangement of the Garden and the introduction of the Linnean system occurred during the professorship of the younger (John) Sibthorp (1784-96). Much of Sibthorp's tenure of office was spent by him in travels in Greece, collecting material for his great *Flora Graeca*. It is difficult to guess what might have been his influence upon the Garden had he lived longer. As he was founder of the Sibthorpien chair of rural economy it is possible that development with attention to experimental work might have taken place. In the event, after 1790, there was no meeting of the Garden committee for 22 years. Sibthorp was succeeded as professor by Dr George Williams, who combined the duties of a practising physician with those of a Sherardian professor. Though an elegant scholar, his practical experience of plants does not seem to have been great. As Sir James Smith, a founder of the Linnean Society, said, 'Botany at Oxford slept.' But a change was coming. It was heralded by the appointment in 1813 of William Baxter as gardener at £50 per annum, and so began an association with the Garden that lasted 58 years.

At first Baxter could do little in the Garden for want of money and backing. The greenhouses, nearly 80 years old, were falling to bits. Their heating arrangements were primitive. An open brazier with glowing coals was wheeled on a trolley round the orangeries in cold weather, and the flood menace was severe. Baxter built up an extensive collection of willows, and devoted much attention to non-flowering plants. It was when the horticultural skill of Baxter was aided by the drive and enthusiasm of Professor Daubeney that the Garden had its second revival, so that by the middle of the century it was regarded as the most remarkable scientific garden in Britain.

C. G. B. Daubeney was educated at Winchester and at Magdalen, where he became fellow in 1815, later proceeding to Edinburgh to study medicine. He returned to Oxford in 1822 as Aldrichian professor of chemistry. He was best known for his work on volcanoes, but as he had published on such diverse botanical subjects as the mineral nutrition of plants, their irritability, and their metamorphoses, he was elected Sherardian professor in February 1834 on the death of Williams. Legend has it that on the very night of his election he was seen in the Garden with Baxter planning its rearrangement by the light of a lantern. Daubeney begged money from his friends and his college, contributed largely himself, and speedily began a reformation. The erection of more modern greenhouses was one of his first actions. He also built a residence for the professor, in part an upper storey to the old orangery (figure 2). In 1840 he became Sibthorpien professor of rural economy, and so for a time held three Oxford chairs simultaneously.

In Daubeney's time the study of botany with organized classes and laboratory instruction did not exist. It was begun in Oxford under his successor, and a science department in the modern sense has developed. When, some 80 years ago, the university was building its science laboratories in the Parks, there was a plan to give up the old Garden and transfer all the university's botanical interests to the Parks, where a new and larger botanic garden would have been possible. The suggestion was hotly debated, but in the end the scheme was abandoned. Although in a short time the department of botany will be transferred to new laboratories in the science area, it is to be hoped that the ancient Physic Garden will long continue to serve the university and the state within its original walls.

Radioactive phosphorus and exchange of lake nutrients

F. R. HAYES and C. C. COFFIN

Information about the fate of phosphorus added to lake water is of particular importance because of the evidence that in lakes the addition of this single element can greatly stimulate production. The results obtained by the authors on the ultimate movement of radioactive phosphorus added to a small lake indicate that ionic distribution occurs many times more quickly than had been supposed, and that depositions and removals take place by exchange.

INTRODUCTION

If one contemplates the improvement of agricultural lands by addition of fertilizers, the elements which come first into consideration are nitrogen, potassium, and phosphorus. It was natural that, in the first attempts to improve the fertility of waters, attention was directed to these substances. There is, however, some evidence (Neess, 1946) that phosphorus by itself can stimulate production in lakes quite as well as mixed fertilizer does. This may be because potassium is present in sufficient quantities, and the availability of nitrogen is stimulated when phosphorus is added (Einsele, 1941).

Experiments on the addition of phosphorus to lakes have, in general, shown that the extra material rapidly and almost completely disappears from the water (Smith, 1945; Orr, 1947). When ordinary phosphate fertilizer is used, the amounts added have often been quite large—up to 10 or 100 times the amount originally found in the water, the latter being of the order of 25 parts per 1,000,000,000, of which nine-tenths is organic. As the remarks to follow will show, the same rapid disappearance is observed even when the amount of added phosphorus is only 1 or 2 per cent. of the quantity already in solution, as in experiments with radioactive phosphorus. The mechanism by which such rapid removal takes place obviously deserves study.

THE PHOSPHORUS-IRON CYCLE

It may be worth while at this point to mention briefly some conclusions reached by Einsele (1936) and Mortimer (1941-2) regarding the mechanism of nutrient exchange. A lake in spring may be considered to have its water saturated with oxygen, and to have a layer of oxidized mud about 1 cm thick at the bottom. In this oxidized layer there

will be insoluble ferric phosphate, while in the deeper layers of the mud there will be soluble ferrous phosphate. The oxidized layer of mud provides a barrier which prevents the phosphorus from reaching the water. As the summer wears on, oxygen becomes depleted in the lower layers of the lake water, which are cold and relatively stagnant. The iron at the mud-water interface becomes reduced to the soluble ferrous state, permitting solution of the phosphate. Thus the ferrous and phosphate ions move upward until, reaching the higher concentration of oxygen at the thermocline, they tend again to be oxidized and precipitated. One possibility under which some phosphate may penetrate to the surface layers occurs by reason of the presence of hydrogen sulphide in the mud. This compound, formed under certain anaerobic conditions, will precipitate the iron and permit the phosphate to reach the surface layers of the lake. (See figure 3.) So much having been learned without the use of radioactive materials, it seemed likely that the tracer technique might provide further information on the movements of phosphorus in lake waters, and on the nutrient cycle generally.

PRACTICAL CONSIDERATIONS

In any country, some of the lakes will be geologically primitive and relatively infertile; such lakes are often found in quartzite and granite areas. Another type of lake is essentially acid-bog in nature, often surrounded by sphagnum, and usually in non-agricultural areas. A third type is the advanced or meadow lake with reedy margins, frequently associated with farming communities. Experiments involving radioactive tracers are likely to be limited to the first two kinds of lakes, for, owing to the health hazards involved, authorities dealing with the distribution of radioactive isotopes are not disposed to grant



FIGURE 1 - Autoradiograph of a frog taken from a lake, 40 days after addition of P^{32} . The concentration of tracer in the skeleton is evident. Exposure fifteen days, on dental X-ray plate.

permission to add such material to waters in a farming community.

Other factors influencing both the type of lake and the element studied will be the rate of decay and the availability of the isotope. Thus it is easier to obtain permission to use relatively large quantities of P^{32} (half-life about 2 weeks) than C^{14} (half-life 5000 years).

EXPERIMENTAL

The first lake experiment with P^{32} was made by Hutchinson and Bowen (1947), who added 10 millicuries to a stratified 14-acre lake in Connecticut, U.S.A. Their results showed mixing in the epilimnion, and they inferred that there was penetration into the hypolimnion. They also record a 1000-fold concentration of material in the tissues of such littoral plants as *Potamogeton* within a period of one week.

In our experiments with lakes, three additions of radioactive phosphorus have been made; they will be described in turn. The first experiment involved the addition of 100 millicuries of P^{32} to a highly stratified acid-bog lake less than an acre in area, and with a maximum depth of 22 feet (Coffin *et al.*, 1949). Samples of aquatic organisms were removed for analysis at intervals,

beginning two hours after the addition of P^{32} . There was a rapid and immediate uptake by zooplankton, sponges, sphagnum, and algae, suggesting that these forms may be able to deal with inorganic phosphorus directly. Rooted plants, such as cranberry and leather leaf, did not show significant activity until two weeks after the experiment began. Fishes, such as *Fundulus* (of which 4000 were added to the lake before the experiment began), and *Notemigonus*, failed to show any measurable activity until several days had elapsed. This suggests that such forms obtain their phosphorus indirectly by feeding on plankton. The distribution of the activity through the organisms was studied by autoradiographs, as illustrated in figure 1, which is a self-photograph of a frog. Systematic sampling of the lake water showed a rapid decrease in the total activity present, 90 per cent. having disappeared within one month. There was no evidence at any time that the added phosphorus reached the deepest waters, although some penetration of the thermocline was observed.

In the second experiment, which was carried out in 1949 and has not yet been published in detail, 100 millicuries of P^{32} were added 3 feet

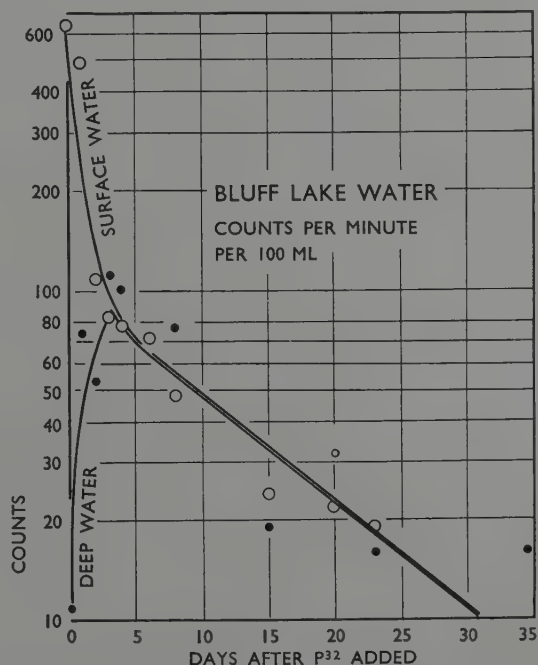


FIGURE 2 - Concentrations of radio-phosphorus in surface water and deep waters of a lake in which complete mixing occurred. Time is measured from the deposition of P^{32} at the surface. The ordinate is logarithmic.

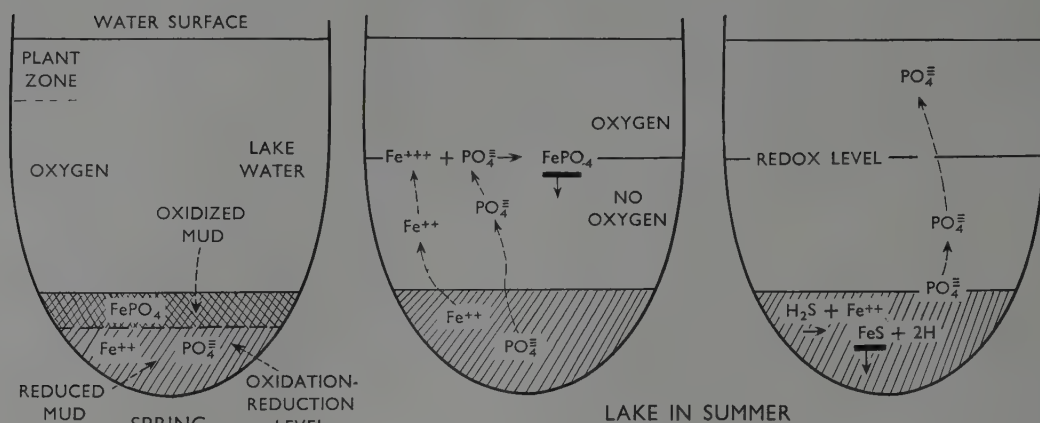


FIGURE 3 - Exchanges between lake mud and water in spring and summer.

above the bottom of the same lake. The material was placed in a large bottle filled with water, and after temperature equilibration the bottle was exploded from the inside with a dynamite cap. Samples were taken at intervals over a period of three months. It was found that the radioactive phosphate moved through the cold layer of water at the bottom of the lake very slowly, the maximum speed observed being approximately five feet per hour in a lateral direction. The movement in the hypolimnion was laminar; thus within two months the added material moved 160 feet in a horizontal direction until it reached the shore, but it did not move in measurable concentrations more than 12 feet vertically upwards.

It was known, as a result of our first experiment, that certain plants have the ability to concentrate phosphorus up to 40,000 times the concentration in the surrounding water. Accordingly, biological samples were taken from the surface waters and analysed for P^{32} . It was found that specimens taken from locations where no radioactive phosphorus could be detected in the water did in fact contain radioactive phosphorus in their tissues. The explanation offered is that these forms are able to extract phosphorus from a larger volume of water than it was possible for us to collect and analyse. The concentration of radioactive phosphorus in the mud reached very high values, indicating that most of the active material added to the lake was removed by the mud.

For the final experiment to be reported, a lake of about eight acres in area and twenty-five feet in depth was selected, of a type providing a complete contrast to the first one. It is a primitive

lake, with little vegetation and no sphagnum, and is completely mixed from top to bottom, so that gradients of oxygen and temperature are not observed at any time. One thousand millicuries of P^{32} were added at the surface, and analyses made at intervals as shown in figure 2, from which it is seen that surface and bottom waters reached equality of concentration within a few days; after that, there was a steady decline. It will be observed that figure 2 has been plotted in a semi-logarithmic manner, suggesting that the removal of P^{32} is more rapid at the start than later on. A remarkable feature of the experiment, which confirms previous observation, was the very rapid disappearance of the activity. This is difficult to understand, because the enhancement of phosphorus in the lake amounted to only about 0.25 per cent. We have been greatly puzzled as to why the added material should appear to be selectively removed. The probable interpretation is that we are not dealing with removal as such, but with an exchange phenomenon in which there is a rapid equilibration between the mud, plants, etc., on the one hand and the water on the other. If, for instance, the mud and living forms contained 1000 times as much phosphorus as the water, and if equilibration between them were rapid, any added material would soon become distributed in the ratio of 1000 parts in the mud to one part in the water. If one were measuring water only, this would be regarded as a great and rapid loss of material. The slope of the line in figure 2 indicates that some 7 per cent. of the P^{32} is removed each day, which points to a complete turnover of phosphorus in the water every

fortnight. Naturally, one particular atom might exchange several times, another not at all.

An understanding of how exchange of ions might be confused with their apparent removal may be illustrated by consideration of money transfers. Suppose that most of the money in a town at any given moment is in the banks. Suppose further that one dispersed a supply of marked banknotes at random through the town. Within a few days, it would be found that under normal processes of commerce most of the marked notes had moved into the banks. This would not mean that the banks were specifically removing marked notes from circulation, or that the ratio of money in the bank to money outside had changed. It would merely be proof that the banks were engaged in active trading, which is the important consideration in the present case.

CONCLUSION

Experiments of the type described, on biological systems generally, have led to two conclusions, the first one being that ionic distributions take place at a rate from ten times to one hundred times greater than had previously been supposed. The second is that depositions and removals of material do not take place separately, but that one should think rather of exchanges. It appears likely that results of the application of tracers to limnological investigations will offer further support to such concepts.

It is a pleasure to acknowledge the support given to our work by the Nova Scotia Department of Trade and Industry, the National Research Council of Canada, and the Nova Scotia Research Foundation.

NOTE ON PHOSPHORUS 32

Phosphorus 32 has a half-life of 14.3 days. It emits only beta radiation, of a maximum energy of 1.7 million electron volts. These beta rays are quite energetic and easily measurable.

The material can be prepared by the action of neutrons on ordinary phosphorus of atomic weight 31, in which case the specific activity, or activity per gram, of the final material is limited, because the product and the target material are identical chemically. It is usual to irradiate red phosphorus in the atomic pile and to dissolve the irradiated material in moderately strong nitric acid, when orthophosphoric acid is obtained labelled with phosphorus 32 at a specific activity of about 10 millicuries per gram.

If phosphorus 32 is required at higher specific activity it has to be made by the (n, p) process on sulphur 32. In this process ordinary elementary sulphur is irradiated in the pile, and some of the sulphur 32 atoms absorb a neutron, emit a proton, and are converted to phosphorus 32. Because the product nucleus differs chemically from the target nucleus it is possible to extract the phosphorus 32 from the sulphur without having a large amount of inactive phosphorus present. This is usually done by melting the sulphur and extracting with nitric acid. Either concentrated acid is used at atmospheric pressure, or dilute acid in a pressure vessel. The phosphorus appears in the aqueous phase as orthophosphoric acid, and can be separated from the other materials present and prepared at very high specific activity. Phosphorus 32 intended for tracer experiments is almost always prepared by the second of these two methods.

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The Science Museum, London

F. SHERWOOD TAYLOR

The Science Museum, London, is one of the most comprehensive of its kind. In the present article the Director, Dr Sherwood Taylor, has not attempted to be lyrical about its treasures and merits, but has given a plain and simple factual account of its chief contents, its organization, and its planned extensions. This account will, it is hoped, be of assistance and value to all those interested in the historical aspect of science, whether in Britain or overseas.

The Science Museum, London, which is the British national museum of science and industry, came into being as a result of the great Exhibition of 1851. The Prince Consort's proposals for the furtherance of industrial education, and the extension of the influence of science and art upon productive industry, led in 1853 to the formation of the Department of Science and Art, an essential part of whose function was to form a museum of science and art. Collections illustrating these subjects already existed at Marlborough House, but were transferred in 1856 to a large corrugated iron building on the site now occupied by the Victoria and Albert Museum. This building was opened in 1857 as the South Kensington Museum. These premises, which from their mode of construction acquired the not inept nickname of the Brompton Boilers, were soon outgrown, new buildings were erected on the same site, and the science collections were later transferred to other buildings on and near the present site of the Science Museum. The science collections were much augmented, especially by the transfer of the Patent Museum in 1883. The most important event in the Museum's history, however, was the separation of the art collections in 1909 to form the Victoria and Albert Museum, and the assumption of the status of a separate institution by the science collections, under the title of the Science Museum. The galleries available were both crowded and inadequate, so for this and other reasons a committee under Sir Hugh Bell was appointed in 1910 to inquire into the organization, aims, and requirements of the Science Museum. As a result of its recommendations, there was begun a series of buildings which even yet is not completed. The eastern block, familiar to all Londoners, was opened in 1928: this is being supplemented by a central block, now in process of construction. A western block is contemplated in due time.

The objects of the Museum are to illustrate and

explain the various branches of science, and their application in the arts and industries, and to afford a worthy and suitable house for the preservation of appliances which hold honoured place in the progress of science or the history of invention. Medicine and biology (except as far as it enters into agricultural technique), and likewise geology, have been excluded from the scope of the Science Museum, as being represented in other national museums, but the whole of the rest of science, pure and applied, lies within its field. The provision of information has likewise been one of the Museum's functions, and the Science Library, which is one of its departments, is one of the chief scientific libraries of Great Britain.

The Science Museum has a larger number of visitors than any other in Great Britain; these range from multitudinous small boys and girls to historians of science and expert engineers, a fact which sets difficult problems in the display of exhibits. Its primary duty is to the general public rather than the expert, and great efforts are therefore made to illustrate the simplest principles of its subjects in the clearest possible manner—especially by working models, which have an intense fascination for the young scientist and engineer. This primary regard for the general public has made the Museum reluctant to form what may be called 'collectors' collections,' exhaustive of their subject: unlike the majority of the museums it displayed in pre-war days 95 per cent. of its total material, and refrained from forming considerable reserve collections for the use of students.

The collections, other than of books, are divided into seven departments: physics, chemistry and photography, land and water transport, mining and electrical engineering, aeronautics and sailing ships, motive power and industries, and astronomy and geophysics.

The present department of physics has for its scope the well-known branches of physics—heat,

sound, optics, electricity and magnetism, with the more modern developments of electron physics and atomic physics. Time measurement, a science based on physical laws, is also included, as are two special historical collections, the H.M. King George III collection and the Rayleigh collection. The H.M. King George III collection consists of a collection of very beautiful scientific apparatus, assembled under the patronage of that monarch and used for the education of the royal children; the small Rayleigh collection consists of home-made apparatus used by the third Lord Rayleigh, and illustrates the versatility of his genius.

The sections relating to the branches of classical physics consist mainly of historical sequences of exhibits showing the development of the various instruments employed in these branches of physics. The collection of microscopes is particularly full, and is probably the most representative in existence. The most remarkable example is perhaps Hooke's microscope, made by Christopher Cock (figure 1), which at one time formed part of the H.M. King George III collection. Occasional explanatory and illustrative exhibits are also included in these sections, and it is intended in the future to increase the number of the exhibits illustrating physical phenomena, as they are educative in themselves and enhance the interest of the more static instrument collections.

The electron physics and atomic physics sections are doing their best to keep pace with these rapidly developing subjects. The range of the time measurement section extends from the water- and shadow-clocks of ancient Egypt to the quartz-crystal clocks of today.

The chemistry collections developed at a later date than those illustrative of physics, and it is only now, with the building of new galleries, that we are able to contemplate the display of industrial chemistry in a worthy manner.

The section on pure chemistry includes many famous exhibits, such as original specimens of Faraday's benzene (1825), Crookes' thallium metal and compounds (1862), Wollaston's rhodium and palladium (1803-4), and the apparatus and spectrum-tubes used by Ramsay and his collaborators in their researches on the rare gases of the atmosphere (1895-8). To the present sections on inorganic and organic chemistry will shortly be added collections illustrative of molecular structure, biochemistry, and analytical chemistry.

The main branches of industrial chemistry have hitherto been illustrated by a series of historical

models; that of the nitroglycerine plant shown in figure 4 is a typical example.

Worthy of mention are complete models of an early sulphuric acid chamber plant and of a Leblanc soda works. The first type of retort used by James Young in 1851 for distilling oil from torbanite can be compared with a modern bench of 'Pumpherson' oil shale retorts. The fermentation processes and manufacture of explosives are well represented, and some of the earliest specimens of artificial silks and dyestuffs are preserved in these collections. Nevertheless, the great advances of the British chemical industry are not yet reflected here, and it is intended that a feature of the Museum's new extension shall be an attractive and modern display of its principles, methods, and products.

Metallurgy is illustrated by models of ancient and modern types of furnaces for the extraction of metals, and plant used in refining processes. The collection includes examples of assaying apparatus, and of atomic models illustrating the structure of metals and alloys.

The organization of photography and cinematography as separate collections dates from 1929. About the same time, the Royal Photographic Society allowed the more valuable historical exhibits in its collection to be shown in the Science Museum; the combined collections constitute perhaps the finest record of photographic history in the world. In kinematography are included many of the earliest inventions. Beginning with the early mechanical devices which preceded the cinema proper, the collection includes cameras and projectors built both before and after the production of the first celluloid film in 1889.

The department of astronomy and geophysics illustrates the subject of the astronomical universe, including a study of the oceans and atmosphere of the Earth, and the properties and measurements of the Earth itself as one of the planets of the solar system. The scope is in fact roughly what would have been covered by the title cosmography in the eighteenth century. The sections include astronomy, geophysics, geodesy, surveying, terrestrial magnetism, geography, oceanography, meteorology, and mathematics.

The mathematical section shows the historical development of the calculating machine, and also drawing instruments and geometrical models; Babbage's original calculating engines are preserved here. Historical telescopes made by Sir William Herschel, Lord Rosse, and others are shown in the astronomy gallery, where there are

sextants, orreries, globes, astrolabes, and numerous transparencies of celestial photographs. Models show the scale of the universe. It is hoped that when the central block is completed we may be able to include a planetarium, and an observatory with a three-foot reflecting telescope for use by the visitors. The geophysics section shows the instruments and methods used in prospecting for oil and minerals, together with working seismographs used for the recording of earthquakes. The surveying and photogrammetric collection contains a good representation of the actual instruments used in the first principal triangulation of the British Isles. It is proposed to develop the section in that part devoted to aerial surveying, and to introduce more cartographic exhibits to make clear the technique of map-making. The historic development of all types of instruments used in meteorological observations is illustrated; the charts used in weather forecasting are displayed; and a set of transparencies shows the most important cloud types and other atmospheric phenomena. Steps are being taken to form a section showing the early history and modern methods of navigation, both marine and aerial.

The engineering collections occupy the greater part of the Museum and are its especial glory. The visitor is greeted on entering the Museum by the view of the East Hall (figure 2), which is devoted to the development of motive power. The exhibits illustrate man-power, water-power, wind-mills, steam engines and turbines, and gas and oil engines. The great steam engines of the eighteenth century are deeply impressive: other monuments of engineering history are an original Trevithick steam engine (1803), the first Parsons steam turbine and high-speed generator (1884), and the first Diesel engine made in Great Britain (1897).

The collection of hand and machine tools shows in the limited space available examples of pre-historic stone implements followed by simple hand tools such as the axe, hammer, chisel, and drill. Several of the earliest machine tools are exhibited, including the bow-lathe, the pole-lathe, Maudslay's original screw-cutting lathe, Roberts' early metal-planer, Nasmyth's original model of his first steam-hammer, and a series of machines designed by Brunel for the mass-production of naval pulley-blocks.

The textile machinery collection naturally starts with the preparation of the raw materials—wool, cotton, flax, silk, and rayon. The development of spinning and weaving is demonstrated by hand spinning-wheels, some original machines

used by Arkwright, and replicas of Hargreaves' spinning jenny and Crompton's mule. A ring spinning frame can be worked to show modern practice.

In the weighing and measuring collection, the evolution of the primary standards is displayed in broad period groupings from about 5000 B.C. to the twentieth century. Exhibits of special interest and importance are some ancient Egyptian and Muslim weights and measures from the Petrie collection, the historic Exchequer primary and secondary standards of England from Henry VII to Queen Victoria, with copies of the modern yard and pound standards, a collection of English bronze wool weights, showing the economic importance of the wool trade in England for over 300 years, and the Royal Society linear standards from 1742 onwards, illustrating the beginning of scientific measurement in Great Britain.

An important section of the Museum is concerned with transport of all types. The section on road transport includes many objects of universal appeal, including Sedan chairs and many types of horse-drawn vehicles of the eighteenth and nineteenth century. The development of the bicycle extends from a hobby-horse of 1818 to the most modern types. Motor-cars begin with a Benz three-wheeler of 1888, still in running order; motor-cycles include a Wolfmüller machine of 1884, and the interesting Werner machine of 1899 (figure 3).

The railway collection includes some of the most famous early locomotives, such as *Puffing Billy*, built in 1813, the remains of the *Rocket* and the *Sans Pareil*, and parts of the *Novelty*, the three engines which competed at the decisive Rainhill Trials in 1829, and the first electric Tube locomotive, built in 1890. The development of the steam locomotive is shown by a series of scale models, from a conjectural model of Trevithick's Penydarran engine of 1804 to those of engines now used by British Railways, while various foreign types are represented by a further series of models. Other subjects dealt with include railway carriages and wagons, permanent way, signalling, and tickets. The collection also contains a fine set of early prints and other documents and relics relating to early railways and railway pioneers.

Among the most noteworthy examples in the powered water-transport collection are Symington's and Bell's original marine engines of 1788 and 1812 respectively, the after portion of the *Turbinia* of 1897 including the steam turbines, a small Daimler internal-combustion marine engine



FIGURE 1 - Hooke's microscope, constructed by Christopher Cock. Originally part of the H.M. King George III collection.



FIGURE 2 - Exhibits in the East Hall illustrating man-power, water-power, windmills, steam engines and turbines, and gas and oil engines.



FIGURE 3 - Werner motor-cycle of 1899. There is a striking resemblance to the power-aided bicycles which are once again becoming popular in Britain and elsewhere.



FIGURE 4 - Model of a nitroglycerine plant.

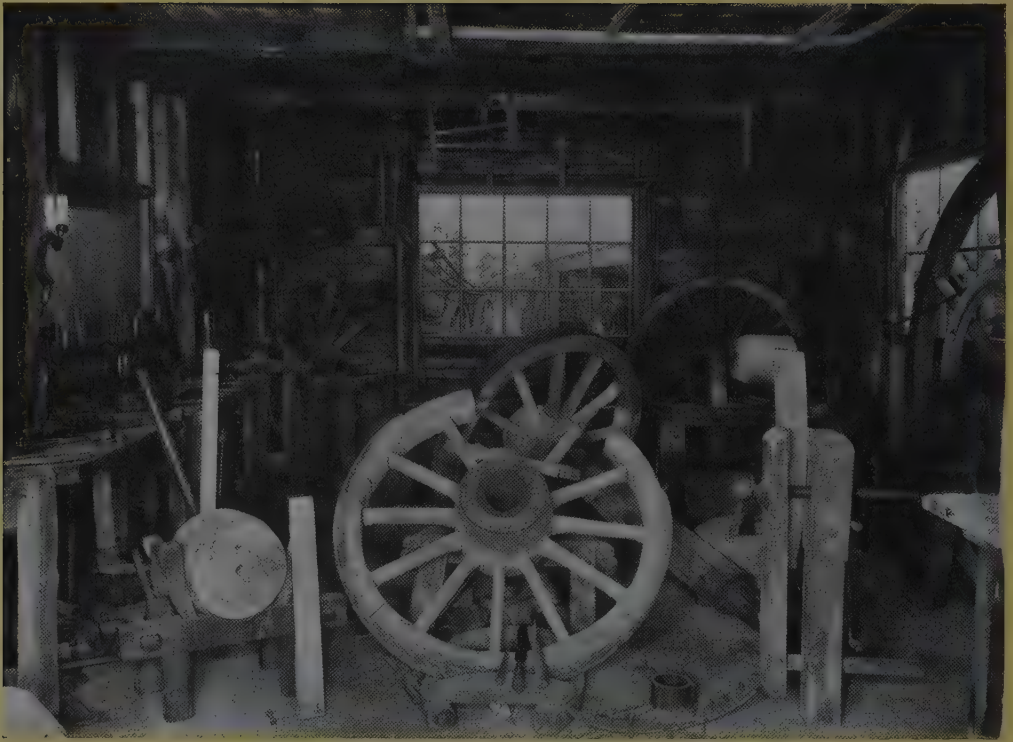


FIGURE 5 - Model representing an early wheelwright's shop.



FIGURE 6 - Model representing a modern coal-mine.

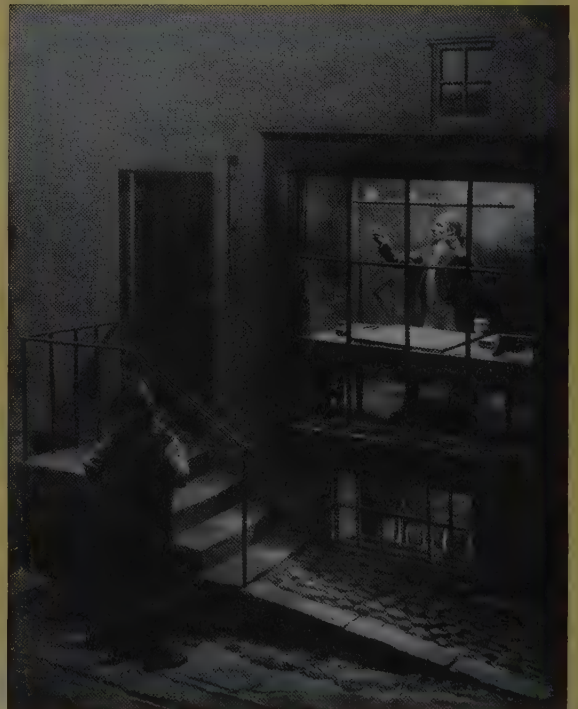


FIGURE 7 - Model reproduction of William Murdock's house at Redruth with the gas lighting plant he installed in 1792.

of 1898, and the gas turbine used in Motor Gun Boat 2009 in 1947. Steamship models form a series covering practically all the important stages of development, while the collection of marine engine models includes many fine examples, such as those of the unique Maudslay collection. The development of paddle wheels and screw propellers, marine boilers, and other accessories is also shown by models and actual examples.

At present, unfortunately, only a proportion of this material can be shown, but with the completion of the central block it is hoped that all the more important objects will once more be displayed.

The aeronautical collection is of comparatively recent origin, but already contains many objects of great historical interest as well as a large number of the most modern types. It is at present shown in premises separate from the Museum, the Western Galleries, but will finally find its home in the new central block. The early models of Stringfellow and Henson, and an original Lilienthal glider (1895), are among the earlier exhibits. The original Wright aeroplane (1903) was exhibited from 1928 to 1948, but has now been returned to the United States and is replaced by a replica. The historic machine in which Alcock and Whitten-Brown first flew the Atlantic is another treasured possession.

The agricultural collections are in a state of rapid development. The Museum has fine historical collections of agricultural tools and machines from the most primitive times. These are being augmented by a striking display of modern farming machinery and methods, which will be displayed to the public this year.

Another very successful display has been created in the new illumination section, where the extensive collections have been rearranged by reducing the number of exhibits and showing them in brightly lit cubicles, interspersed with dioramas to give a better idea of the effectiveness of the lighting that could be obtained from the apparatus available at various periods of history.

One of the most interesting developments of recent times is in connection with the expansion of the collection dealing with gas manufacture and distribution. In 1937, on the initiative of the late Thomas Hardie, at that time chief engineer to the Gas Light and Coke Company and a member of the advisory council of the Museum, a committee representative of gas producers and gas plant manufacturers was formed, and was charged with the task of creating a collection of exhibits worthy of the industry. This provides a notable example

of collective effort on the part of the industry for the benefit of the Museum's permanent collections. Considerable funds were subscribed, and the scheme was well under way when war broke out. The committee has recently been reorganized under the auspices of the Institution of Gas Engineers, and development is actively proceeding on the basis of increased financial resources provided by the Gas Council. A large gallery, at present in course of completion, has been allotted to the subject, and the display will be on modern lines. It is expected that the work will have advanced sufficiently to enable the gallery to be opened in May or June this year.

Mining, though of such great national importance, has hitherto been poorly represented in the Museum. It is hoped, however, to open new mining galleries in the basement early next year, the main feature being a realistic representation of the galleries of a coal mine, with about 70 yards of roadway and a coal face of some 30 yards. Full-sized equipment will consist of conveyors, coal-cutters, cage, tubs, etc. This work is being carried out by the Museum with most valuable assistance from individual manufacturers of mining equipment. There will also be a metalliferous stope.

Electrical engineering is another important subject which, though rich in historical material, is poorly represented on the modern side. It is due for reorganization, so that its technical achievements and general significance may be better understood by the Museum's visitors, and a committee of the Institution of Electrical Engineers, on which all sides of the industry are represented, is assisting the Museum in this task. A gallery of 10,000 sq ft will be made available for the purpose when the Festival of Britain authorities release it.

The Museum possesses much valuable material illustrating the history of line telegraphy and telephony, and of radio communication, and a selection of apparatus developed during the war.

With the increase in the number of visitors which followed the opening of the new galleries in 1928, it was felt that something more should be done for the young, and those unacquainted with the principles of science. This led to the setting out of a Children's Gallery, designed to make them see the development of science as a connected whole, by means which make a strong appeal to children, such as dioramas and working exhibits. The printed guide to this gallery forms an admirable short introduction to the development of science, as is shown by the fact that some eighty thousand copies have been sold.

It is evident that considerations of space alone prevent the full and detailed display of modern scientific and technological developments. No more than a selection or general outline of these developments can be given in the permanent collections. The Science Museum recognizes an obligation, however, to do more than this, and accordingly from time to time special temporary exhibitions are held, lasting from a few weeks to perhaps six months, the purpose of which is to bring to the notice of the public all that is new in some relatively restricted field. A large number of such exhibitions have been held during the last thirty years, dealing with such varied subjects as geophysics (1924), adhesives (1926), glass technology (1931), very low temperatures (1936), television (1938), illumination (1950), and submarine cables (1950). The Museum is greatly indebted to industrial and scientific bodies and individual firms, who commonly shoulder a very considerable part, and in many cases a predominant part, of the expense and labour of organizing these special exhibitions, a commendable feature of which is the anonymity of individual exhibitors. Temporary exhibitions of a different character are those marking anniversaries of notable achievements in the fields of pure or applied science, and the exhibition recently held for the exclusive benefit of blind persons and those with impaired vision.

With the Science Library we pass, in conclusion, to a unit with an impact on the scientific world rather different from that of the rest of the Museum. The Science Library started well back in Victorian days, but it began to play its present highly significant role only during the late twenties of this century, when it first lent widely to scientific institutions and industrial research units (though not to individuals). At the same time it began rapidly to expand its holdings, especially of periodicals. It covers every subject in pure and applied science except medicine, though it has never catered for the more elementary reader.

The loan system was, from the first, the sort of runaway success which is perilously near to a disaster: borrowers were constantly on the point of using their privilege so freely that the unfortunate visitor to the reading room too often found

the fatal notice 'On loan' confronting him. Until the second world war, however, this peril was kept in check, and the library, with its practice and advocacy of modern techniques of classification, information service, and the like, became a centre of pilgrimage for librarians from all over the world. Even the outbreak of war did not at once reveal the difficulties which lay ahead: readers naturally diminished in numbers, while the service to borrowers became a major asset to the nation, when so many new research units completely without library resources were being started for urgent war necessities. It was only after the war, when difficulties multiplied everywhere, that the demands on the library became almost unendurable in their effect on readers, and indeed on borrowers too. The library has brought into being a photocopy service and a co-operative lending service among its borrowers in an effort to check the chronic over-use of its collections, but years of work remain to be done, not least in reader-education, before it can measure up to the need which it has striven to supply and has no doubt in part created.

We have now surveyed the multifarious activities of the Science Museum and turn to look to its future. If the country's urgent needs do not prevent the fulfilment of the plans for the Museum's development, we look forward to a great extension both of the subjects illustrated and of the number and variety of exhibits used to that end. Whatever the rate of its expansion, however, the Science Museum will play its part in that revolution in museum technique which is going on all over the world at the present time. The *gazophylacium* and 'cabinet of curiosities,' beloved of the seventeenth century, gave way to the scientifically ordered but lifeless assemblages of objects characteristic of the nineteenth. Today we are discarding 'collections' in favour of integrated displays, designed not so much to show things as to express ideas by them, and by every device capable of making impressions on the human mind. Nor are these expressions of ideas to be simply intellectual, for we seek to appeal not only to the intellect that grasps the concepts of science, but to the aesthetic and emotional powers which lend significance to those concepts and make them a part, not only of the system of science, but also of the life of man.

The physics of clouds and their precipitation

P. A. SHEPPARD

Studies of the physics of clouds carried out within the last decade have thrown much light on the processes involved in precipitation, and lead to the conclusion that in most instances a raindrop originates as an ice crystal. This has led to attempts to initiate the precipitation of clouds artificially, either by the creation of ice nuclei or by the introduction of crystals, such as those of silver iodide and cadmium iodide, which possess a very similar crystal lattice.

Clouds are formed in the atmosphere by the quasi-adiabatic cooling of moist air due to its ascent; the form of the cloud depends on the nature and pattern of the vertical motion. If the latter should extend over a large horizontal area, of the order of 10,000 sq km or more, the vertical velocity is generally quite slight—no more than a few cm/sec—and a cloud of layer-type (stratus cloud) will be formed. If, on the other hand, the upward motion is quite local, of the order of 1 sq km, the velocity being large (up to 1000 cm/sec) or small, a heap of cloud (cumulus cloud) will be formed. Continuity and the conservation of mass demand that in both cases there should be descending air near the rising current. The descent involves compression and heating, and consequently evaporation of any cloud previously formed in the descending air; it is generally more gentle and extensive than the corresponding ascent.

This broad classification requires subdivision if it is to encompass adequately all the varied forms of cloud. Thus, lesser movements are often associated with the main one, giving rise to combinations of layers and heaps (stratocumulus, altocumulus, and cirrocumulus cloud), while, as will be discussed later, the temperature of formation and the depth of the rising current exert profound influences on the form and life-history of a cloud.

THE GROWTH OF CLOUD DROPLETS

We know, from the work of C. T. R. Wilson and others, that cloud droplets will not form in pure moist air which has been cooled, unless the relative humidity rises to a value several times that of saturation; the condensation then occurs on gaseous ions. Such supersaturations never occur in the atmosphere, because it always contains a more or less plentiful supply of microscopic or ultra-microscopic particles, often hygroscopic, upon which

condensation can occur at relative humidities which need be at the most only slightly above 100 per cent. For the larger, hygroscopic particles Wright [1] and others have shown that condensation occurs at appreciably lower humidities. Some of these nuclei of condensation are particles of common salt of the order of $1\ \mu$ or less in diameter; Dessens [2] has caught the droplets on fine spider-thread (see figure 3) and examined their behaviour in an atmosphere the humidity of which was controlled. They often remain liquid at humidities far below the equilibrium value for a saturated solution of salt, and then consist of droplets of supersaturated solution. Sooner or later, however, crystallization sets in; the larger the droplet the more readily it occurs, and it happens with explosive violence, so that several smaller nuclei are produced simultaneously. Simpson [3] has argued that the oceans cannot produce salt particles at a rate fast enough to provide all the centres of condensation necessary in air in which cloud is formed, and from which the water is later precipitated. Oxides of nitrogen, formed presumably in lightning discharges and later dispersed widely, may perhaps provide alternative, but smaller, hygroscopic centres, while dust particles which can be wetted may act as non-hygroscopic nuclei. Further work is needed to solve the problem, but we may proceed by assuming that there is, in the rising air mass, a supply of condensation nuclei of various sizes at a concentration rarely numbering less than a few hundred per cubic centimetre. The number of nuclei can be measured with an Aitken nucleus counter. In populated areas, there are generally many thousands per cubic centimetre, formed as a result of combustion, but most of them are very small and probably unimportant.

The process by which hygroscopic nuclei grow in a rising current may be inferred from figure 4a,



FIGURE 1 — An example of cirrus (ice-crystal) cloud which has resulted from the earlier formation of supercooled water-droplet (cirrocumulus) cloud. The transformation is almost complete but a patch of cirrocumulus remains (top centre) and an element is in process of transformation on the lower right-hand side of this patch (see arrows). At temperatures of formation below -40°C the precursor liquid phase is less readily seen.



FIGURE 2 — A cumulonimbus cloud, with well-developed anvil, which has been more or less completely transformed to ice. The cloud has probably passed into the decay stage, though rain continues to fall from the base.

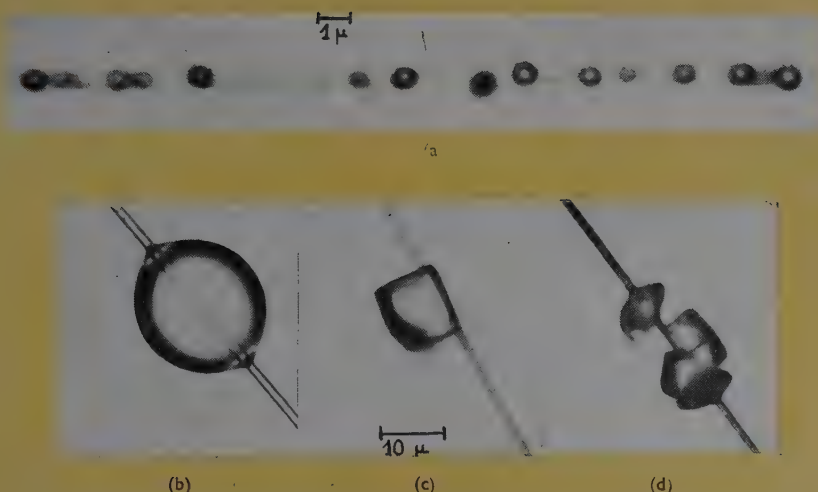


FIGURE 3—(a) Photograph of the larger droplet-nuclei from haze. (b), (c), (d) Photographs of a large droplet-nucleus before (b) and after (c, d) desiccation. Note the splitting in (d). (After Dessens.)

(Figures 1, 2 and 3 by courtesy of the Royal Meteorological Society.)

which shows the equilibrium humidity over drops, containing varying concentrations of solute, as a function of their size. Two opposing effects determine the form of these humped curves: the depression of vapour pressure over a salt solution, which for a given drop is greater the more concentrated the solution, and the elevation of vapour pressure over a curved surface of pure liquid, which increases as the size of the drop diminishes (Kelvin effect). Note that each curve lies wholly above or below the next, and that the hump of supersaturation fades out for the nuclei containing larger amounts of solute. Condensation will occur on any drop if the actual vapour pressure in the air exceeds the equilibrium value for its radius, and the rate of increase of diameter is proportional to this excess vapour pressure, and inversely proportional to the diameter. This follows from the law of diffusion to a spherical body. The extent of the excess vapour pressure will in turn depend on the rate of ascent and the temperature, i.e. on the rate at which water vapour becomes available for condensation, on the number of drops per unit volume, and on their diameter (figure 4*b*). The growth-rate can then be readily calculated.

An actual case, in which nuclei of different sizes and different concentrations are involved, is more complex. All nuclei initially grow as the humidity rises to near-saturation, but only those in which the solute exceeds a certain concentra-

tion are able to surmount the hump in the equilibrium curve, because the actual super-saturation will depend on how rapidly the available water vapour is taken up by the faster-growing nuclei. For those which pass over the barrier, the growth rate thereafter depends on diameter in two opposing ways: the excess vapour pressure is greater over the larger drops (cf. *BB'* and *CC'* in figure 4*b*), but for a given excess of vapour pressure the smaller drops increase their diameter by diffusion more rapidly than do the larger ones. Differential growth rates are therefore not obvious, and only detailed computations for given nuclear spectra, rates of ascent, and temperature can enable the outcome to be predicted.

Such computations have been made by Howells [4] for low, moderate, and high rates of ascent, assuming a range of nuclei likely to be encountered in practice; he finds a strong tendency towards homogeneity in a cloud quite early in its history. Only the largest, amounting to between 10 and 20 per cent. of the total nuclei, become drops; the higher rates of ascent involve the greater fraction of nuclei and the greater uniformity of size of drops. The latter conclusion receives support from the appearance of lenticular altocumulus clouds in the standing waves which form down-wind from some topographical features. Very considerable vertical velocities are encountered in these waves, and the clouds show coronal iridescence,

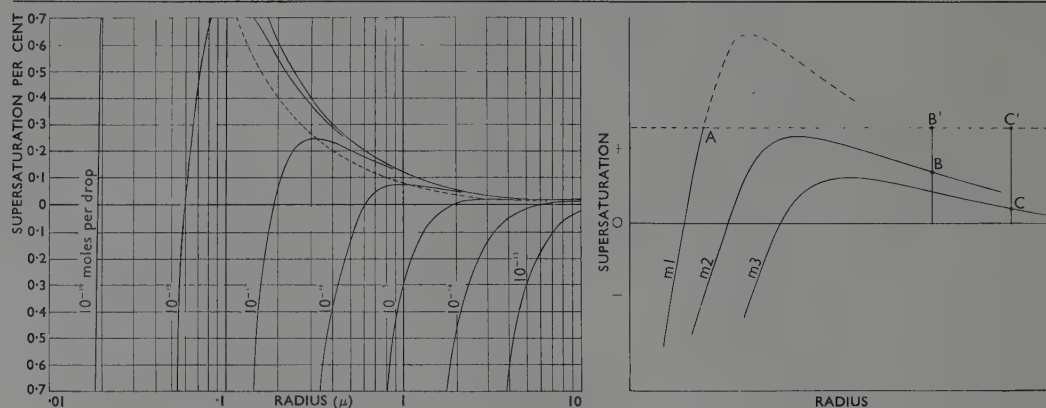


FIGURE 4—(left) Equilibrium humidity, shown as departure from saturation over a plane surface, for drops of water containing given amounts of dissociated solute, measured in moles per drop and thus independent of the nature of the solute (after Howells). (right) An exaggerated portion of graph to show the growth process. The horizontal broken line represents the humidity in the environment of the drops at a given instant. Nucleus m_1 is in equilibrium with its environment at A and does not grow; nuclei m_2 and m_3 are assumed to have reached the points B and C respectively and are subject to excess vapour pressures represented by BB' and CC' , and they therefore grow.

indicative of cloud homogeneity. Howells finds the supersaturation in a growing cloud to be small at all times, with a maximum of about 1 per cent. in rapidly rising currents.

Observations on the diameters and concentrations of droplets in clouds are still rather few and perhaps not very reliable. There are usually a few hundred drops per cubic centimetre, with diameters covering a considerable range at any one part of the cloud. There are, however, always fairly well-defined maxima in the diameter-distribution and drop-volume-distribution curves—evidence of the tendency towards homogeneity. The position of the maximum varies from one part of the cloud to another, and depends on cloud type. It is found that the diameter of droplets may vary from about $2\ \mu$ to $50\ \mu$ (or more in precipitating clouds) with the diameter of the drop with median volume generally falling to between about $6\ \mu$ and $30\ \mu$. In this respect clouds range themselves roughly in the order: stratus (minimum), stratocumulus, cumulus, altocumulus, nimbostratus, cumulonimbus (maximum). See Bricard [5], Diem [6], and Lewis and Hoecker [7].

The distribution of drop-size will be modified near the edges of cloud by turbulent mixing with clear air, causing a wider range of sizes, and to some extent also within the cloud by the collision of drops, a process calling for further investigation. Most workers are at present agreed that collisions are too infrequent to modify appreciably the basic distribution within the lifetime of most cloud droplets, provided that large drops are not produced.

We may show by a simple argument that large drops are not readily produced by a condensation process. Consider, for example, a very favourable case in which warm air of high relative humidity, and therefore of high absolute humidity (say 25°C , 70 per cent. humidity), and with low effective nucleus content (100 per cubic centimetre), is transported upwards to such a height that practically all the water vapour is condensed. The resulting drops, assumed to be uniform, will, it may be shown, attain a diameter of less than $70\ \mu$. For comparison, a drizzle droplet has a diameter of $200\ \mu$ or more. Such sustained ascent would, of course, take the air to levels at which the temperature is well below 0°C , but supercooling to a minimum of -30°C is fairly general in the atmosphere, so that the assumption that water is condensed throughout the ascent considered is reasonable.

We are thus led to the conclusion that clouds of water drops are in general colloidally stable, and may not produce rain unless there is present some agent, so far unconsidered, that will cause an aggregation of the cloud droplets. One such agent is ice, and this leads us to discussion of the production of clouds containing ice-crystals.

ICE CLOUDS

We have just remarked that water droplets supercool in the atmosphere. They are also formed on nuclei at sub-zero temperatures, but it appears that below about -40°C condensation always occurs in the form of ice, giving rise to those beautiful thread-like cirrus and halo-forming cirrostratus

clouds of high levels. Even here, however, the evidence is that an ice crystal forms only on a nucleus which is first appreciably wetted in an atmosphere saturated with respect to water, i.e. about 50 per cent. supersaturated with respect to ice (see figure 1). The atmosphere is frequently supersaturated with respect to ice, but unsaturated with respect to water, without ice cloud being present. Persistent aircraft condensation trails show up this state of affairs. The aircraft exhaust provides sufficient water vapour to produce saturation with respect to water in the aircraft's wake; the nuclei then grow and an artificial ice cloud is formed. Fournier d'Albe [8] has watched this process with the ultramicroscope, using an expansion-chamber in which the end-point could be closely controlled at the frost-point or dew-point of the air. He found that whereas ice only was formed at temperatures below -41°C , a few ice crystals appeared among many more water droplets in the range -32° to -41°C when uncleaned air was used. He also discovered two kinds of artificial nuclei, silver iodide and cadmium iodide, possessing much higher threshold temperatures for ice formation, about -7° and -9°C respectively, the latter temperature, however, only if the cadmium iodide had first been activated at -41°C or below. Moreover, this salt then behaved as a true sublimation nucleus, i.e. it became active at the frost-point; it is the only sublimation nucleus, apart from ice itself, so far discovered. Both substances have lattice constants quite close to those of ice I.

Findeisen [9] had earlier discovered the existence in the atmosphere of ice-forming nuclei which become active at about -10°C , but in concentrations so low (of the order of one per litre) that they could not be found in Fournier d'Albe's small expansion-chamber. They are, as we shall see, likely to be of great importance in promoting colloidal instability in supercooled-water clouds. There is no definite knowledge of the nature of any of the ice-forming nuclei in the atmosphere, but Mason [10] has made tentative inferences. The expansion-chamber technique so far used in their examination involves the equivalent of excessively high rates of ascent of air, and, as Findeisen found the activity of nuclei to depend on the rate of expansion, there must be some hesitation in applying the results of such research directly to the atmosphere. We may infer, however, that most, if not all, clouds of supercooled drops will contain a very small percentage of ice particles at temperatures between about -10°C

and -30°C , and a greater percentage below -30°C . At temperatures below -41°C all clouds are probably composed mainly if not wholly of ice.

THE PRODUCTION OF PRECIPITATION

We have already seen the relative humidity in a cloud composed of water to be practically 100 per cent. with respect to water, and the presence of relatively few ice crystals cannot substantially alter that state. Such ice crystals therefore find themselves in a supersaturated atmosphere, and consequently grow at the expense of the water droplets, the maximum growth rate, *ceteris paribus*, occurring at -12°C . Growth being rapid, they quickly acquire a substantial rate of fall relative to the surrounding cloud droplets, and a sweeping action ensues, so that growth is much enhanced. In deep layer-type clouds (nimbostratus), with small rates of ascent of air, these units of precipitation are mainly snowflakes, while in vigorous convection clouds (cumulonimbus) they are more likely to be graupel (granular snow pellets or soft hail), since these are the preferred forms when growth is rapid. Melting will of course begin as soon as 0°C is exceeded during their fall, and, if cloud extends below this level, growth will continue by the sweeping action alone, which preponderates from a much earlier stage. The precipitation may reach the ground as rain if there are a sufficient distance and rise of temperature between the 0°C level and the ground.

The essence of these ideas was first put forward by Bergeron in 1933. They may be summarized thus: every raindrop originates as an ice crystal. It has recently been shown that the concentration of ice-forming nuclei at the higher temperatures is of the right order of magnitude for the process described, though other processes of rain-production should not necessarily be excluded. For example, there is accumulating evidence that some convection clouds, particularly in the tropics, produce rain without rising above the 0°C level. Ludlam (unpublished) has suggested that this may happen when there is a small fraction of particularly large hygroscopic nuclei which grow preferentially, and, in moving up and down vertically, remain long enough in the cloud to grow to the size of raindrops, even large raindrops, by sweeping action alone. The circumstances require quantitative treatment before a conclusion can be reached. It is readily shown that sweeping action may produce a rapid rate of growth. Thus if there are relatively few larger drops, of diameter D , falling through a cloud of smaller drops

whose liquid water content is w per unit volume of cloud, the rate of increase of D is of the order of $0.5w$ per unit distance of fall relative to the small drops. Taking a quite moderate value for w of 1 gm per cubic metre in a convection cloud, the rate of diameter growth is 0.5 mm per kilometre.

Ludlam [11] has also pointed to the possibility of a chain reaction in cumulonimbus clouds. Initially small graupel or hailstones may collect water by sweeping at so fast a rate that the latent heat of fusion may not be entirely dissipated, and supercooled 'raindrops' stream from the rear of the element. These may grow by further sweeping action, become unstable and break into smaller drops, and so on. In that case the ice crystals appearing near or at the summit of a cumulonimbus cloud (figure 2) perform no necessary function in the main release of precipitation, though they may account for the rather light rainfall in the decay period of a storm. When the concentration of ice particles is high, the Bergeron process must in any case be less effective, for there is then much less water available per ice crystal than when the ice crystals are rare.

ARTIFICIAL PRECIPITATION

The realization that precipitation is produced by a trigger action has led to much recent work, initiated by Langmuir, on the artificial triggering of clouds. This has taken two forms—the unloading of small pellets of solid carbon dioxide from aircraft into supercooled clouds, and the introduction of silver iodide nuclei from the ground into clouds by convection. The carbon dioxide pellets produce a copious supply of ice crystals in their wakes by local cooling, and large patches of a supercooled layer-cloud may thus be dispersed by transforming the cloud into snow. It also appears that large cumulus clouds have been caused to rain by the same method, or by silver iodide inoculation, but it must be realized that such clouds might produce precipitation in any case—there is only a quite narrow band of cloud-top temperatures in which artificial seeding can be

used to anticipate natural seeding. If, however, seeding is not the only possible method of triggering a cloud, as is indicated by the natural precipitation from unglaciated clouds, the possible scope of artificial precipitation is somewhat widened. Whether precipitation is produced naturally or artificially, a large quantity of liquid water must be present in a vertical column drawn through the cloud. It is aided by high temperature at the base (high dew-point of the air supply), great depth (long distance in cloud for embryo precipitation elements to fall through), and large upward vertical velocity (long time of fall of precipitation elements through a given depth of cloud).

NEW METHODS OF CLOUD INVESTIGATION

The experiments recently undertaken on the artificial precipitation of clouds may be regarded as an extension of the usual physical laboratory procedure of controlled experiment, which is not often applicable in meteorology. Thus, whatever may be their outcome so far as rain-making (or even rain-prevention) is concerned, meteorologists should learn much about cloud physics from such experiments.

Centimetric radar has recently placed another powerful tool in the cloud physicist's hand. A cloud scatters back radar pulses according to the Rayleigh law, that is, with an intensity proportional to $\Sigma(nd^6)$, where n is the number of drops of diameter d in the beam. Thus radar provides a technique of cloud exploration (particularly for cumulonimbus, for which the aeroplane is a rather fragile tool) which is particularly suited for the identification of larger cloud elements and so can be applied to the study of precipitation growth, echoes being obtainable from particles of both water and ice. The life-cycle of cumulonimbus clouds is of the order of an hour, and so can be followed on a single radar set. Much has been learnt about this cycle since the war, but only passing reference (Sheppard [12]) can here be made to it.

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Antibacterial substances from lichens

FLORENCIO BUSTINZA

Recent investigations have shown that crude extracts of many lichens, and some of the individual lichen acids, such as usnic acid, have considerable antibacterial activity, including activity against the tubercle bacillus. Experiments with animals indicate that some of these substances may prove suitable for chemotherapy, particularly for combating infections resistant to currently used drugs. These interesting discoveries give some justification for the traditional use of lichens, in many different countries, for treating certain pulmonary affections.

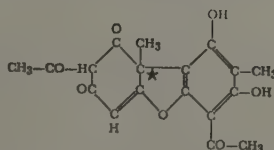
There are not many references to the use of lichens in medicine in ancient times. It has been recorded that while travelling in the Nile Valley in 1864 Schweinfurth found a fragment of lichen in a vase of the 18th dynasty (approximately seventeenth century B.C.). This lichen was identified by Muller as *Evernia furfuracea* (L.) Ach. It is interesting to note that a crude extract of this species has recently been shown [1] to be active against the bacterial species *Staph. aureus*, *Bacillus mycoides*, *B. licheniformis*, and *Mycobacterium phlei*. Another lichen, *Lobaria pulmonaria* (L.) Hoffm., has a long-established reputation in medicine; from the 17th to the 19th centuries *Cetraria islandica* (L.) Ach. was widely prescribed for the treatment of pulmonary tuberculosis. In 1802 the French military physician J. B. Regnault published an interesting work entitled *Observations on pulmonary consumption or an essay on the lichen islandicus considered both as an aliment and as medicine in that disorder*. This species was included in many pharmacopoeias until quite recently, and it is interesting to note that crude extracts of it inhibit the growth of many bacteria, including several species of *Mycobacterium*.

In modern times Burkholder and his collaborators [2] were the first, in 1944, to call attention to the antibacterial activity of different lichens. They used for their assays, made by the usual plate and cylinder method developed for penicillin, crude extracts prepared by grinding up freshly gathered lichen with phosphate buffer at pH 7.4. As test organisms they used *Staph. aureus*, *B. subtilis*, *P. vulgaris*, *Str. faecalis*, and *E. coli*. A later paper [3] described additional tests made not only with fresh lichens but also with dried material from various collections. Of the several hundred species tested, fifty-two proved to be active against *Staph. aureus* or *B. subtilis*, but the great majority proved inactive against Gram negative bacteria; the exceptions are tabulated in the next column.

ACTIVITY OF LICHENS AGAINST
GRAM NEGATIVE BACTERIA

Lichen species	Active against
<i>Cladonia delicata</i> ; <i>Cladonia glauca</i> ; <i>Parmelia conspersa</i> ; <i>Parmelia rupestris</i> ; <i>Thamnolia vermicularis</i> ; <i>Xanthoria parietana</i> ..	<i>A. faecalis</i>
<i>Cladonia borbonica</i> ; <i>Parmelia rupestris</i> ..	<i>E. coli</i>
<i>Parmelia physodes</i> ; <i>Umbilicaria papulosa</i> ..	<i>P. vulgaris</i>

The discovery of antibacterial activity in lichen extracts prompted examination of some of the individual lichen acids. The first of these was isolated by Pfaff in 1826 from *Cetraria islandica*. In 1843 Rochleder and Heldt isolated, from *Usnea barbata*, the important substance usnic acid, the



chemical nature of which has been studied by Curd and Robertson and Schöpf and Ross. Hesse and Zopf subsequently isolated many more. The Japanese workers Asahina, Asano, and their co-workers have made detailed studies of the chemical nature of lichen products, and Asahina himself has made a notable contribution in this field by the development of microchemical methods for identifying lichen acids.

Burkholder and his co-workers showed [3] that a saturated aqueous solution of usnic acid is active against *B. subtilis* but inactive against *E. coli* and *Staph. aureus*; atranorin and fumarprotocetraric acid are inactive against both these bacterial species. In 1945 Barry and McNally [4] reported only slight activity of roccellic acid (α -methyl- α' -n-dodecyl-succinic acid) against *M. phlei* and *M.*

tuberculosis bovis. They found high activity in the monoesters and the monoamide of this acid, which is produced by *Lecanora sordida*.

Nolan and his collaborators have studied the chemical nature of diploicin, derived from *Buellia canescens*; they showed that it is a depside containing three organic chlorine atoms. In 1946 Barry tried to test its antibacterial action but found that it was insoluble in water; mild treatment with alkali, however, led to the appearance of a phenolic and a carboxylic group, and the derivative had a water-soluble sodium salt. This was active *in vitro* against *M. smegmatis*, *C. diphtheriae* (*mitis*), and *M. tuberculosis* [5].

In 1946 Bargellini *et al.* [6] showed usnic and vulpinic acids to be active against *Staph. aureus*, *C. diphtheriae*, and *B. subtilis* but not against Gram negative bacteria.

Early in 1947 Marshak published interesting work on a crystalline antibacterial substance obtained from *Ramalina reticulata* (Noedh) Krempf. At a dilution of 1 : 20,000 this substance inhibited various species of *Pneumococcus*, *Streptococcus*, and *Staphylococcus*. At a dilution of 1 : 50,000 in Dubos medium various strains of *M. tuberculosis* were inhibited; in some tests appreciable inhibition was found even at 1 : 2,000,000. *M. tuberculosis avium* was more resistant to usnic acid than was *M. tuberculosis hominis*, as in Dubos medium it was necessary to have a concentration of 1 : 20,000 to obtain even partial inhibition of the *avium* strain. In an attempt to protect guinea-pigs against virulent strains of *M. tuberculosis* he concluded that a dose of 25–50 mg per kg of body-weight could be given daily, by subcutaneous injection in oil, without toxic effect. When so given to guinea-pigs infected intraperitoneally with human tuberculosis, the progress of the disease appeared to be retarded [7]. Subsequently Marshak [8] identified his material as the *dextro* isomer of usnic acid.

In 1947 Stoll and his collaborators described [9, 10] results of tests on 58 lichen species, of which 38 proved active against *Staph. aureus*; they discussed also the activity of usnic acid against *Mycobacterium* and other organisms (figure 5). This was the first published work to mention the activity of *Cetraria islandica* (figure 4), *Cladonia rangiferina*, *Lobaria pulmonaria*, and *Parmelia furfuracea* against *Staph. aureus*. These workers also described for the first time the extraction of *dl*-usnic acid from *Cetraria islandica*, the yield being 0.04 per cent.; they showed that its antibacterial activity is independent of its optical activity. All forms of usnic acid inhibited strains of *M. tuberculosis hominis* and

M. tuberculosis bovis at dilutions ranging from 1 : 500,000 to 1 : 800,000. It was also shown that vulpinic, *d*-protolichestic, dihydrolichestic, physodic, and diffratic acids are all more or less active against *Mycobacterium* and Gram positive cocci. In 1947 Barry and his collaborators [11] reported the anti-tuberculous activity of usnic acid at dilutions of 1 : 500,000. In 1948 Ciferri and Giacomini published the results of a survey of 231 different lichens.

The author's own investigations in this field began, with A. Caballero, towards the end of 1947. Attention was first directed towards the activity of *Evernia furfuracea* and *Evernia prunastri*, using as test organisms *Staph. aureus*, *B. mycoides*, *B. licheniformis*, and *M. phlei*. From *Evernia furfuracea* we isolated an antibacterially active fraction rich in ergosterol; from *E. prunastri* we obtained usnic acid [1]. We also studied the antibacterial activity of *Usnea florida* (L.) Hoffm., and obtained from it *d*-usnic acid in yields of 3.8–4.1 per cent. of dry matter. The activity of this substance against *Staph. aureus* and *M. phlei* was assayed; when it is added as a fine powder to broth *Staph. aureus* is inhibited at a dilution of 1 : 50,000 and *M. phlei* at 1 : 100,000. *M. tuberculosis avium*, in glycerine broth, is completely inhibited at 1 : 100,000 and partially so at 1 : 200,000. In Dubos medium, however, much higher concentrations (1 : 20,000) are necessary to effect inhibition; a similar effect was noted with *M. tuberculosis hominis*. In glycerine broth this is inhibited at 1 : 500,000, but in Dubos medium a tenfold increase in concentration is necessary for the same result. When using the plate and cylinder method of assay for sodium usnate, large and very clear zones are given by 1 : 10,000 solutions, using *M. tuberculosis avium*. We have also described the formation of a precipitate, thought to be streptomycin usnate, when sodium usnate is added in aqueous solution to streptomycin hydrochloride. This substance, which we have used as a suspension in phosphate buffer or oil, or in solution in propylene glycol, is characterized by being active against all the species of *Mycobacterium* which were tested and in addition it is active against *E. coli* (figure 1). Since the publication of these results I have been able to demonstrate the presence of streptomycin in this precipitate by using it (figure 2) to promote the growth of streptomycin-dependent strains of *E. coli*. Conversely, the presence of usnic acid in the precipitate is demonstrated by the fact that it inhibits the growth of the pathogenic fungus *Tricophyton mentagrophytes*, which is susceptible to usnic

acid but not to streptomycin (figure 3). At the time of writing it is not clear whether this precipitate is a chemical combination of usnic acid and streptomycin, or whether it is merely a physical combination held together by adsorptive or similar forces.

Curiously enough, at the same time as this type of research on lichens was being pursued in Europe and the United States, Japanese workers independently entered the same field. In 1948 Shibata and his colleagues [12] published the results of research on the antibacterial activity of *laevo*, *dextro*, and *dl* usnic acid and some of their derivatives, the latter including *l*-diacetylusnic acid, *d*-diacetylusnic acid, *l*-dihydrousnic acid, and *d*-diacetyldihydrousnic acid. Their results are tabulated below.

Derivative	Inhibiting titre	
	<i>Staph. aureus</i>	<i>M. tuberculosis avium</i>
Usnic acid	1 : 160,000—1 : 320,000	1 : 160,000
Diacetylusnic acid	1 : 10,000—1 : 25,600	1 : 40,000
<i>l</i> -Dihydrousnic acid	1 : 10,000—1 : 25,600	1 : 40,000
<i>d</i> -Diacetyldihydrousnic acid . .	1 : 6,400—1 : 10,000	1 : 10,000

These results suggest that the double bond and the hydroxyl groups contribute in large measure to the antibacterial activity of usnic acid. Marshak and his colleagues have since confirmed that any major alteration in the usnic acid molecule reduces or destroys its activity.

Shibata and his colleagues refer to the use of *Usnea longissima* in China as an expectorant, and for the local treatment of ulcers. They also state that more than fifty years ago tincture of *Usnea* spp. was successfully used for the treatment of tuberculosis lymphadenitis. In a subsequent publication Shibata and Miura [13] described an investigation of the action of 23 lichen products against *Staph. aureus* and *M. tuberculosis avium*. These substances had very varied chemical structures and included lactic fatty acids, depsides, depsidones, and an anthraquinone derivative. They also found high antibacterial activity in certain tetronic acid derivatives, such as protolich-estric acid, and in certain depsides and depsidones related to orcinol. Later [14] they reported that didymic acid and a derivative of it are active against Gram positive bacteria; these substances contain the dibenzofurane nucleus.

In 1948 Klosa [15] gave an account of the anti-

bacterial properties of a substance, which he named evosin, derived from one of the *Usneaceae*; evosin is in fact a mixture of usnic acid, evernic acid, and two other unidentified substances. Evosin is very active against both staphylococci and streptococci; it inhibits the growth of *M. tuberculosis* at a dilution of 1 : 2,000,000. Klosa states that evernic acid inhibits the same organisms at dilutions of 1 : 1,000,000. In subsequent publications [16, 17] he describes the successful clinical use of evosin in various skin diseases, such as lupus vulgaris, furunculosis, and impetigo, and in the treatment of bovine mastitis.

Vartia [18] states that in Finland hot aqueous extract of reindeer-moss (*Cladonia alpestris*, *Cladonia rangiferina*, or *Cladonia sylvatica*) is traditionally used as a remedy for tuberculosis. Of 82 species tested usnic acid was found in 22. These 22 species were all active against *Sarcina aurea*, *Staph. aureus*, *Strep. pyogenes*, *B. subtilis*, and *B. megatherium*; the majority were also active against *C. diphtheriae*. He also records that twenty species of lichens inhibit *P. vulgaris* and generally also *E. coli*; nine of these species contain atranorin. From atranorin he obtained a crystalline derivative which inhibits *Proteus vulgaris* at a dilution of 1 : 10,000.

In a survey of the antibacterial activity of *Cetraria islandica* Vartia found it to be active against *Sarcina aurea*, *Staph. aureus*, *Strep. pyogenes*, *E. coli*, *P. vulgaris*, and *B. megatherium*. *Cladonia rangiferina* does not attack these organisms, according to Vartia, and Evans and Burkholder [3] state that *Staph. aureus* and *B. subtilis* also are not inhibited by this lichen; this conflicts with Stoll *et al.*, however, who found that *Staph. aureus* was attacked. Vartia also reports antagonism between the two groups of lichens and fungi tabulated below.

Lichen-fungus antagonism	
Lichens	Fungi
<i>Cetraria glauca</i> <i>Parmelia stenophylla</i> <i>Evernia prunastri</i> <i>Usnea dasypoga</i> <i>Alectoria sarmentosa</i>	<i>Actinomyces sulfuroides</i> <i>Tricophyton farinaculatum</i> <i>Tricophyton interdigitalis</i> <i>Epidermophyton inguinale</i>

Vartia states [19] that the sodium salts of protolich-estric, divaricatic, and physodic acids are active against Gram positive bacteria. Pätälä confirms (private communication) Marshak's

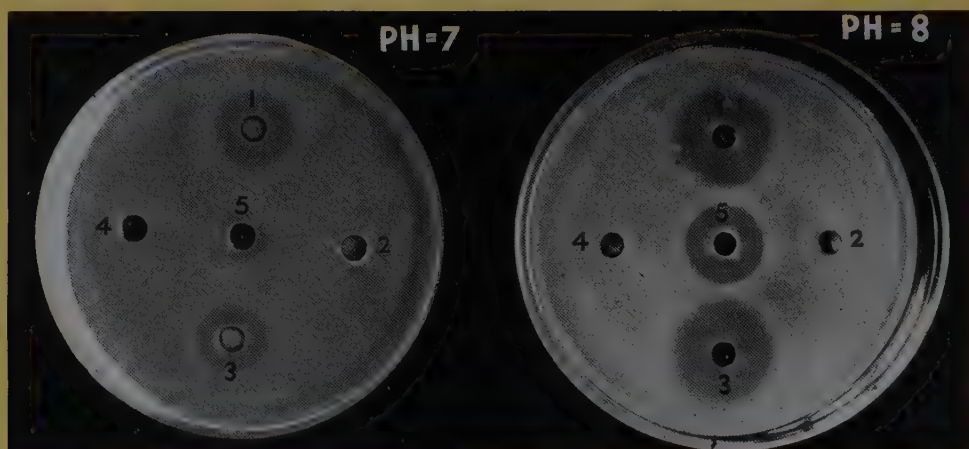


FIGURE 1 - Effect of pH on activity of streptomycin and streptomycin usnate. (1) and (3) contain a 0.1 per cent. suspension of streptomycin usnate; (2) contains a 0.1 per cent. solution of sodium usnate; (4) contains a 0.1 per cent. dispersion of usnic acid; and (5) contains aqueous streptomycin solution containing five units per c.c. The test organism is *E. coli*.

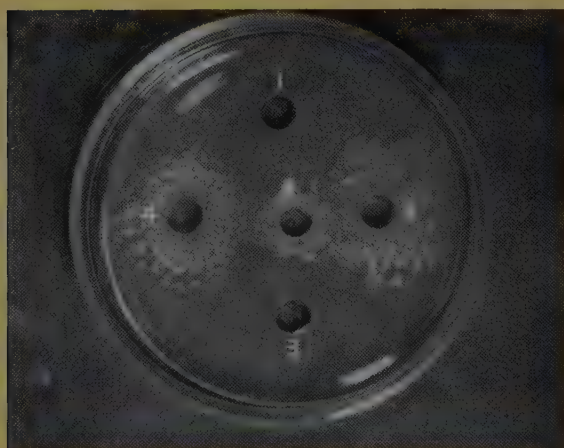


FIGURE 2 - Plate seeded with streptomycin-dependent strain of *E. coli*. (1) and (3) contain 0.1 per cent. sodium usnate solution; (2) and (4) contain a 0.1 per cent. suspension of streptomycin usnate; (5) contains streptomycin solution containing eight units per c.c.

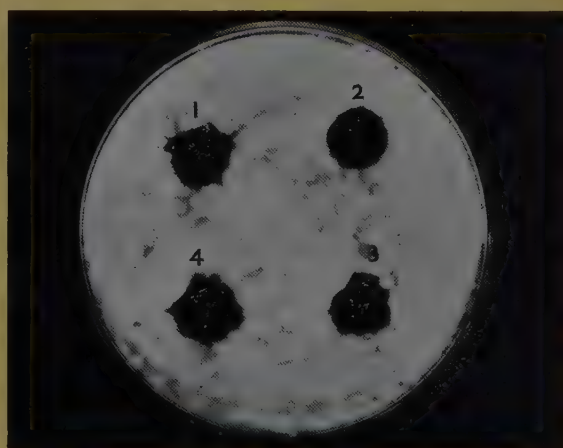


FIGURE 3 - Plate seeded with *Tricophyton mentagrophytes*. The holes were filled with a 0.1 per cent. solution of sodium usnate.

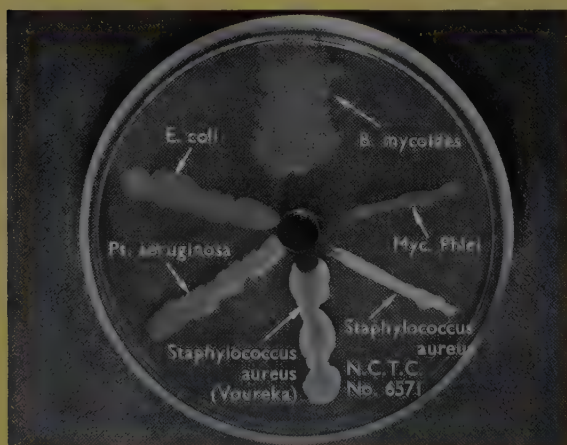


FIGURE 4 - Illustration of the inhibition of a number of bacterial species by a crude extract of *Cetraria islandica*. Note that *E. coli* and *Ps. aeruginosa* are not inhibited at all.

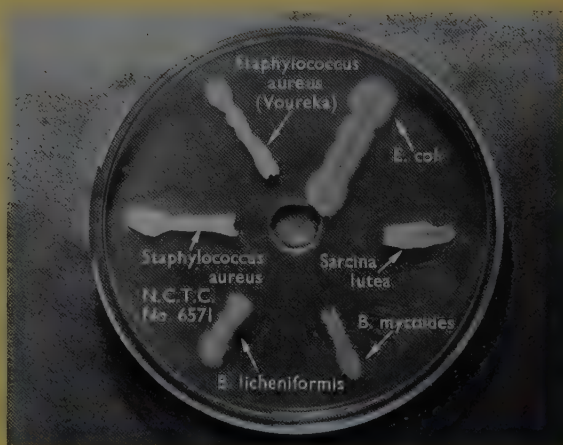


FIGURE 5 - Illustration of inhibition of a number of bacterial species by 0.1 per cent. sodium usnate solution. *Staph. aureus* (Voureka) is a penicillin-resistant strain. Note that *E. coli* is not inhibited at all.

observation that usnic acid retards the development of tuberculosis in guinea-pigs.

In more recent trials by Marshak and Kuschner [20] of the therapeutic value of usnic acid and streptomycin in treating tuberculosis in guinea-pigs, they conclude that 'although the results obtained show that streptomycin alone in sufficiently large doses is more efficient than usnic acid . . . the observed synergistic action of the two drugs makes it probable that the development of resistance, a serious problem in therapy, may be limited through the combined action of both substances.' This result is in agreement with my own prediction of 1948.

Despite the considerable amount of work reviewed here, which has led to the discovery of several promising new antibacterial substances, of which usnic acid has been the most closely studied, it is still not clear whether these substances are derived from the lichens as a whole or from the symbiotic fungi which form an integral part of them. Ashly, for example, has shown that the mono-methyl ester of emodine obtained by Raistrick and his collaborators [21] from *Aspergillus glaucus* is identical with the product named physcion (= parietin) from *Xanthoria parietina*. Thomas [22] indicates that pure cultures of *Caloplacomycetes*, a fungus occurring in many lichens of the genus

Caloplaca, and also *Xanthoriomyces parietinae*, found in the lichen *Xanthoria parietina*, can produce physcion. From the fungus *Candelariellomyces vitellinae*, obtained from the lichen *Candelariella vitellinae*, he has isolated the substance stictaurin. Previously both stictaurin and physcion were regarded as products of the lichen rather than of the fungus. Castle and Kubsch [23] have isolated usnic, didymic, and rhodocladonic acids from the fungus found in the lichen *Cladonia cristatella*.

It is clearly of the greatest interest, in view of the promising results already obtained and the very urgent need for substances which will attack Gram negative bacteria, to continue a systematic study of the antibacterial and antifungal activity of the thousands of known lichen species; an important precaution which must be taken is to ensure that pure species and not mixtures are examined. Further, it is necessary to prepare and examine pure cultures of the fungi found in those lichens which yield substances likely to be of practical value. It may be that the fungi symbiotically associated with lichens will prove an important source of new antibiotics, some of which may be added to those which have already established themselves in medical practice. On the other hand, the lichens as lichens may prove a source of equally useful new substances.

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The permeability of animal tissues

G. M. WYBURN and P. BACSICH

The mucopolysaccharides, the protein-carbohydrate complexes which form the ground substance of connective tissue, are of great physiological importance. Besides influencing the permeability of tissues, they are concerned in immune reactions and enzyme systems. Enzymes, such as hyaluronidase, which can break down mucopolysaccharides, have remarkable powers of increasing the permeability of tissues, and are used therapeutically to hasten the absorption of subcutaneous injections as well as for treating certain types of male sterility.

Cells, fibres, and intercellular material are the structural elements of the tissues of the body. Epithelial tissues form the lining membranes of internal and external surfaces and the functional structure of glands. They consist of sheets or columns of cells held together by a small amount of intercellular material or cement. The connective tissues include the supporting structures of the body, such as bone, cartilage, tendons, and ligaments, and the different types of tissues of loose or dense texture forming capsules, sheaths, and the general packing tissue of the body. These connective tissues are made up of a varying proportion of cells, fibres, and intercellular material or ground substance. The cells are generally discrete, and may be widely scattered, as in bone. The fibres may form a loose, wide-meshed network (for example, areolar tissue), or they may be aggregated in bundles to form a dense feltwork, obscuring the cells and ground substance, as in tendons and ligaments. The intercellular material or ground-substance of the connective tissues ranges from a semi-fluid consistency of varying viscosity to the solid matrix of bone, hardened by the incorporation of mineral salts.

The skin consists of (a) an external cellular epithelium, the epidermis, with a minimum amount of intercellular ground-substance, and (b) a deeper connective tissue, the dermis, where the fibres and cells are set in a more plentiful ground-substance. Over most of the body the skin is freely movable on an underlying, loose, subcutaneous tissue made up of cells and fibres scattered throughout an abundant ground-substance.

The permeability of a tissue is a passive, physical quality, distinct from the vital cell activities of secretion and absorption, and determined by the amount and consistency of the ground-substance. Epithelial tissues with their small amount of intercellular cement have a low permeability, while

the most permeable tissues are those with few cells and fibres and a large quantity of ground-substance of low viscosity—for example, subcutaneous tissue. The connective tissue in general offers considerable resistance to penetration by foreign fluids, and this resistance is an index of its permeability.

There are wide variations in the permeability of the different tissues, and even of the same tissues, such as skin, in the different regions of the same individual. There are also considerable differences in tissue-permeability between individuals, determined to some extent by sex, age, hormone activity, and particularly by the sex hormones and the vitamins such as vitamin C.

Chemically, the ground-substance of the connective tissue, and probably also of the intercellular cement of epithelial tissues, belongs to the group of protein-carbohydrate complexes known as the mucopolysaccharides. Protein-carbohydrate substances have important functions in many aspects of animal economy; for example, they are concerned in immune reactions and enzyme systems, and their particular properties are due to the presence of bound protein or peptide residues. The mucopolysaccharides have a low protein content and are predominantly carbohydrate. Their aqueous solutions have a high viscosity, and they tend to become insoluble in water after dehydration.

Mucoproteins form another group of protein-carbohydrate compounds. They have a relatively high protein content and predominantly protein reactions. Gonadotropic hormones (from the pituitary gland), saliva, serum extracts, and the jelly of jelly-fish, are examples of mucoproteins. The mucopolysaccharides of tissue ground-substance are hyaluronic acid, and the sulphuric esters chondroitin sulphate, mucoitin sulphate, and hyaluronic acid sulphate (which is a mucoitin sulphate); they contain hexosamine and uronic

acid. All, or any combination, of these substances may occur in a particular type of tissue.

Heparin, which is a natural blood anticoagulant widely distributed throughout the body, particularly in the liver, is a mucopolysaccharide containing a high proportion of sulphuric ester. Tissues whose ground-substance contain the sulphate mucopolysaccharides stain with metachromatic dyes such as toluidine or methylene blue. Sulphate-free hyaluronic acid does not give this histochemical reaction. Hyaluronic acid, while present along with other mucopolysaccharides in the ground-substance of connective tissues, is most abundant in the jelly-like vitreous humour which fills most of the eyeball; in the early umbilical cord connecting the embryo to the placenta; and in the lubricating synovial fluid in the cavity of movable joints. Hyaluronic acid sulphate is the mucopolysaccharide of the ground-substance of the cornea, the transparent covering of the front of the eye, and is responsible for its metachromatic staining. Chondroitin sulphate is the most readily accessible mucopolysaccharide occurring naturally. It is one of the major constituents of the ground-substance of cartilage, tendons, large blood vessels, and connective tissue generally, which therefore stain metachromatically.

The mucopolysaccharides have an architectural function in tissues. The most direct way of evolving bulk and viscosity is by polymerizing hexoses and sustaining them in water to form either a refractive medium (such as the vitreous humour of the eye and the synovial fluid of joints) or the undifferentiated substance of intercellular spaces.

It has been suggested that connective tissue cells secrete, into the surrounding tissue spaces, hyaluronic acid and a chondroitin sulphate, together with a precursor of collagen. By local acidification in the neighbourhood of the cells, the first fibres are produced by the action of the polysaccharides on the collagen, and the polysaccharides remain as a layer on the surface of the fibres. The production of mucopolysaccharides is probably a continuous process in metabolically active tissues such as the skin.

Any substance which acts chemically on mucopolysaccharides will alter the physical nature of the ground-substance and affect its viscosity, and thus also its permeability. Certain mucolytic enzymes found in animal tissues act on the mucopolysaccharides. They do this by breaking down the chemical linkages of the large asymmetrical polysaccharide molecules, and so increase tissue permeability largely by reducing viscosity. The

first phase of this process is a depolymerization, and the final breakdown is of the nature of a hydrolysis. This reduction into simpler molecules effects a physical change in the ground-substance, which becomes less viscous and more permeable. The enzyme which has hyaluronic acid as its substrate is known as hyaluronidase, but as its action is not specific—for it can also break down the sulphate-containing mucopolysaccharides—it is probable that hyaluronidase includes a number of mucolytic enzymes. Because of their remarkable power of increasing tissue-permeability, these enzymes are known as spreading-factors.

Hyaluronidase is found in a number of tissues and organs, and enzymatic spreading activity has been demonstrated in extracts of such organs as testis, spleen, ciliary body, and iris. Both snake-venom and bee-venom possess spreading activity, and it is also exhibited by certain pathogenic bacteria. *In vitro*, mucolytic enzymes appear to act in three stages: (a) a separation of the protein residue, (b) a rapid depolymerizing action on the polysaccharide with diminution of the viscosity of aqueous solutions, and (c) a partial or complete hydrolytic action with liberation of N-acetyl-D-glucosamine and D-glucuronic acid. Their activity can be tested *in vitro* by physico-chemical methods, of which three have been described:

1. *The viscosity-reducing method.* One unit of the enzyme is defined as the amount required to reduce viscosity of the substrate mixture to 50 per cent. within 30 minutes.
2. *The mucin-clot prevention method.* Hyaluronic acid in an acid solution precipitates with protein to form a typical mucin-clot. Incubation with hyaluronidase first reduces the clot and the precipitate then ultimately clears.
3. *The turbidimetric method.* This method is based on the fact that depolymerized hyaluronic acid forms a clear solution with dilute serum, whereas pure hyaluronate is turbid.

In vivo activity can be tested by the spreading reaction. A dye, or Indian ink, is injected subcutaneously. Normally, after such an injection a blister remains, and the ink diffuses very slowly. If hyaluronidase or other spreading-factor is injected along with the ink, the blister flattens rapidly, and the ink spreads through the skin like fluid dropped on a blotter. If the animal, usually a rabbit, is killed 20 minutes after the injection, the minimal diffusion dose is the least amount of the enzyme which will produce a 20 per cent. increase in the average area of spread. If the animals are

killed 24 hours after the injection, one finds that the ink has penetrated into the fascia and even into the muscle underlying the injected site. This spreading reaction can be obtained by other non-specific agents.

Hyaluronic acid has been extracted from the vitreous and aqueous humour in various animals, and hyaluronidase has been recovered from the ciliary body and the iris of the eye. There is some evidence for the constant production of hyaluronic acid in the eye, and its simultaneous removal, presumably by enzymatic hydrolysis. It is quite possible that this mechanism is in some way concerned with the maintenance of the normal tension of the eyeball. An abnormal increase in intra-ocular tension, resulting in the condition known as glaucoma, may well be related to some lack of equilibrium in the hyaluronic acid and hyaluronidase system. The polysaccharide of the corneal ground substance (hyaluronic acid sulphate) shows metachromatic staining by virtue of the sulphuric acid radical. The refractory media of the eye (cornea, lens, aqueous and vitreous humours) are avascular, and the continuous process of formation and breakdown of the polysaccharides of their ground-substance may have a nutritional significance. Considerable quantities of hyaluronic acid and chondroitin sulphate can be obtained from the skin. There is also a large concentration of hyaluronidase in the skin, which suggests a fairly rapid production and destruction of hyaluronic acid. It has been shown that, after injection of a spreading-factor, the skin barrier is reconstituted by production of new hyaluronic acid, and restoration is complete within 48 hours. This turnover is influenced by certain hormones. For instance, there are phasic changes in the sex skin of monkeys and apes corresponding to the sexual rhythm, and these involve alterations in the quantity and quality of mucopolysaccharides in the skin. In the turgescient sex skin of a baboon there is, during menstrual cycles, no free fluid, but water is bound by hyaluronic acid. These changes can be produced experimentally by injection of the appropriate hormone.

Hyaluronidase can be obtained from extracts of testes; the normal source of supply is bull testes. It is now known that hyaluronidase is formed in the seminiferous tubules of the testes, where the spermatozoa mature, and is conveyed to the sperms. The ovum, when shed into the Fallopian tube, has a thick covering or capsule of so-called follicular cells, which are cemented together by a

viscous substance. This cellular capsule must be removed before the male sperm can penetrate and fertilize the ovum. Although only one sperm fertilizes the ovum, great numbers of them accumulate in the vicinity of the egg, and liberate the pre-formed enzyme. In a general way, the concentration of hyaluronidase is correlated with the number of sperms present. The cementing substance, binding the sticky mass of cells surrounding the ovum, is a mucopolysaccharide. The function of the hyaluronidase is to act on this polysaccharide, loosen and disperse the covering follicular cells, and so permit early fertilization of the ovum by the sperm. For example, without fertilization, i.e. in the absence of hyaluronidase, these covering cells adhere to the ovum for from six to eight hours, whereas following fertilization, i.e. in the presence of hyaluronidase, they disperse in about two hours. Modern work has shown that the optimum viability of the ovum is probably a matter of hours. It is therefore of importance that fertilization should not be delayed. The absence of hyaluronidase from the testes of birds, amphibia, and reptiles, is correlated with the lack of any capsule of follicular cells around their ova.

It is possible that deficient hyaluronidase is an occasional cause of male sterility. This is likely to be associated with a low spermatozoa count, but the accompanying enzyme deficiency may be a significant factor. Attempts have been made in such cases, before having recourse to artificial insemination, to produce a fertile mating by the addition of hyaluronidase to semen which has failed. Successes have been reported.

Pathological change in the connective tissues is the essential lesion in rheumatic diseases, including acute rheumatic fever, rheumatoid arthritis, and the great varieties and degrees of fibrositis grouped under the name of rheumatism. These changes include alterations in the quality and quantity of the mucopolysaccharides of the ground-substance. In affections of the joints, the synovial fluid contains an excess of hyaluronic acid. In this connection, recent work has shown that cortisone (compound E, the steroid from the cortex of the suprarenal) and adreno-cortico-trophic hormone (the secretion from the pituitary, which controls the secretion of cortisone), may act by protecting the connective tissues against the effects of whatever factor is responsible for the conditions in which the normal chemistry of the mucopolysaccharides has been disturbed. Changes in mucopolysaccharides are also an important part of the pathology of ageing and hardening arteries.

FIGURE 1—Section of testicle. In this field there are cross-sections of several seminiferous tubules, most of them showing active spermatogenesis (production of male germ cells). Apart from this function, the cells in the seminiferous tubules are responsible for the production of hyaluronidase, the presence of which is necessary in the semen of most mammals for the accomplishment of fertilization. This enzyme is probably produced by the Sertoli or nursemaid cells which are scattered in small numbers among the germinal elements of the tubule. The small groups of cells (interstitial cells), visible in the loose connective tissue among the tubules, produce the male hormone. ($\times 110$)

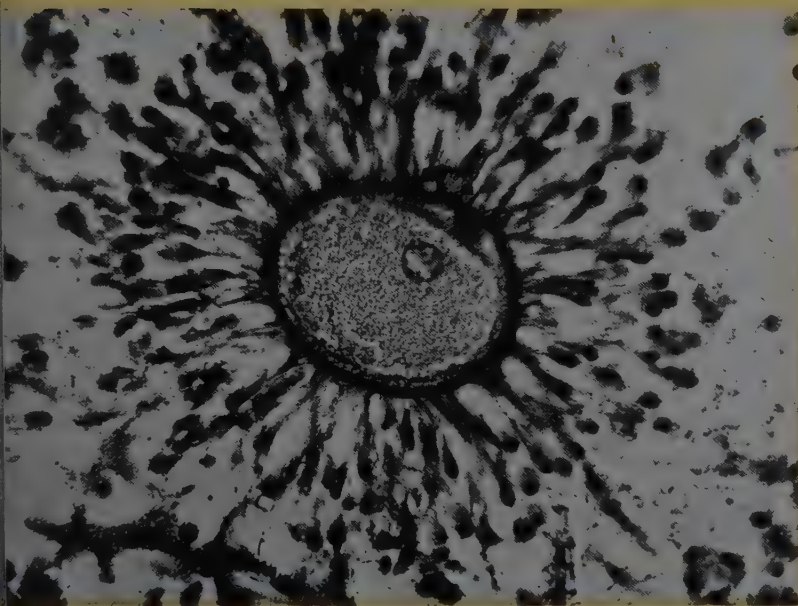
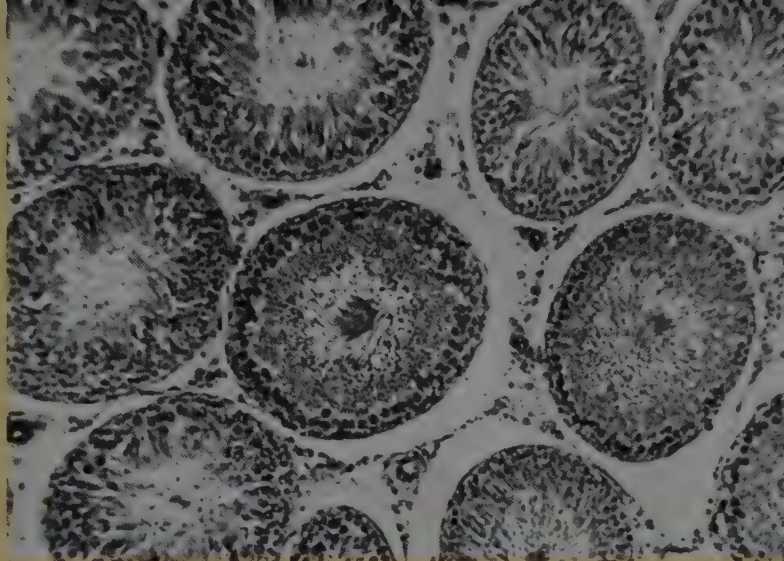
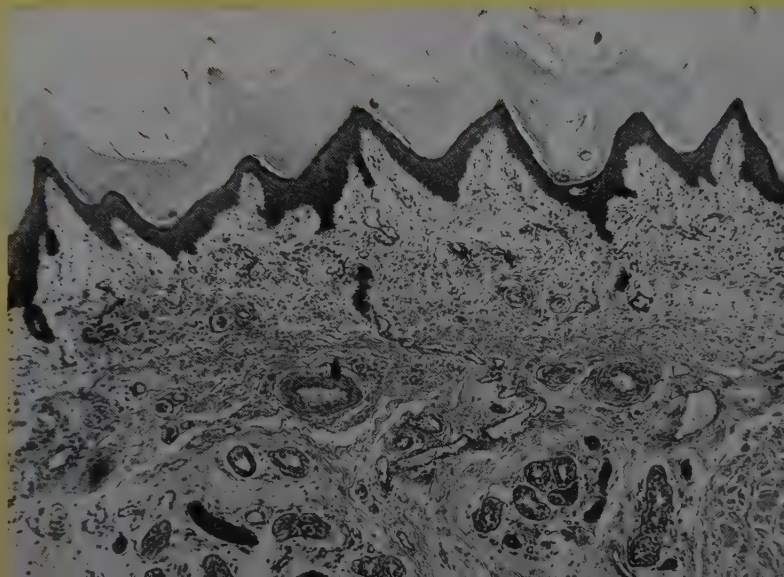


FIGURE 2—Section of a freshly discharged ovum (female germ cell). The ovum at this stage is surrounded by several layers of smaller cells derived from the ovarian follicle. As these cells would hinder fertilization they are gradually removed through enzymatic hydrolysis of the intercellular cementing substance by the action of hyaluronidase, brought along by the spermatozoa. ($\times 300$)

FIGURE 3—Section of skin. The surface of skin is covered by several layers of closely packed epithelial cells (epidermis) with very little intercellular substance. The uppermost layers of these cells are extensively cornified, consequently the epidermis protects the underlying soft parts (the dermis) from mechanical and chemical injury. The dermis contains numerous connective tissue cells and formed connective tissue fibres embedded in a hyaluronic acid jelly. The amount of this hyaluronic acid ground substance is noticeably reduced in exophthalmic goitre (increased activity of the thyroid gland) and consequently the skin as a whole becomes thinner. In myxoedema (reduced function of the thyroid gland) there is an accumulation of hyaluronic acid in the skin, which becomes thicker. These conditions strongly suggest the importance of the thyroid gland in the hyaluronic-acid/hyaluronidase relationship. ($\times 52$)



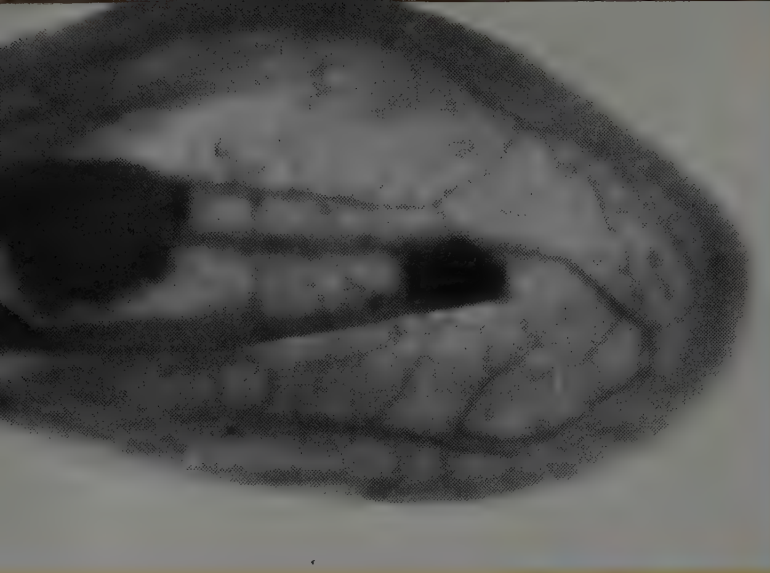


FIGURE 4 - Photograph of a transilluminated rabbit ear to illustrate the spreading effect produced by hyaluronidase 20 minutes after the subcutaneous injection of two equal quantities of Indian ink. The smaller of the two dark patches is the result of injection of Indian ink diluted with physiological saline, while the larger one is produced by Indian ink diluted with a solution of hyaluronidase. ($\times 1.125$)

FIGURE 5 - Surface view of the endothelial cells on the posterior surface of cornea. The intercellular substance (specially stained) forms only a thin cementing layer between the neighbouring cells. The anterior surface of the cornea is covered by several layers of epithelial cells. The main part of the cornea is formed by a jelly of sulphate of hyaluronic acid in which scattered corneal cells and fibres are embedded. There are no blood vessels in the cornea, as the mucopolysaccharide (sulphate of hyaluronic acid) maintains an avascular nutrition. ($\times 225$)

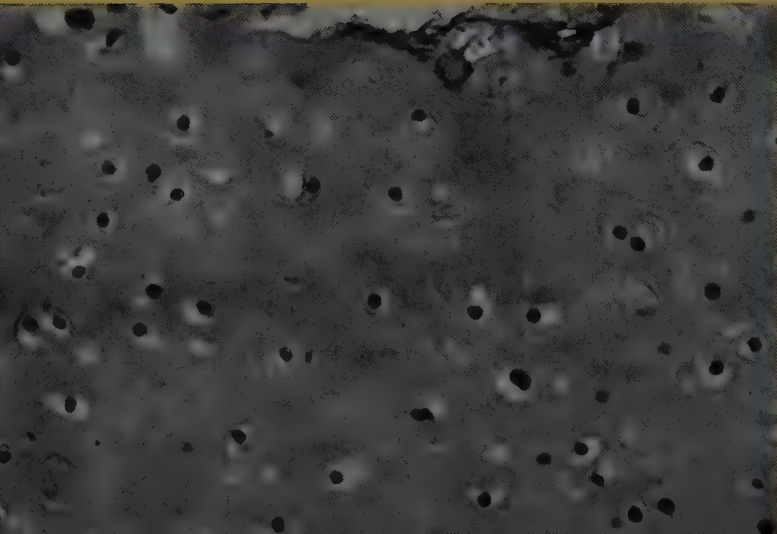
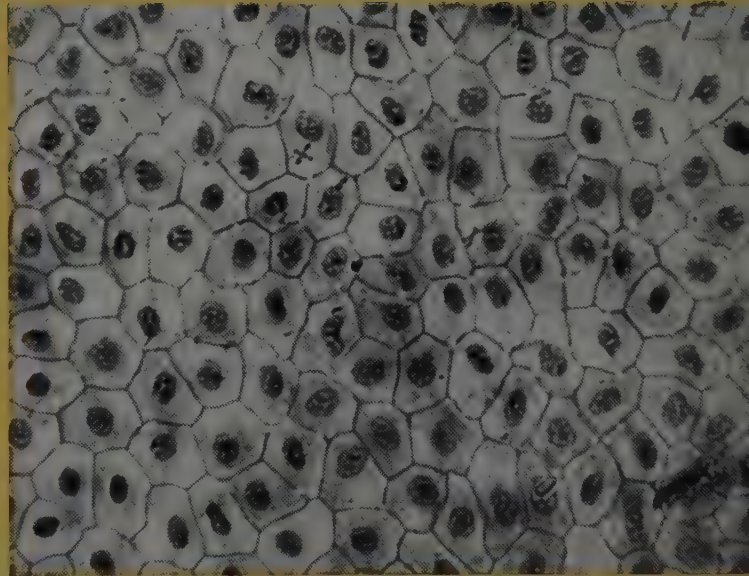


FIGURE 6 - Section of hyaline cartilage. The ground substance is chiefly composed of a mucopolysaccharide, chondroitin sulphuric acid. In this ground substance are embedded small numbers of cartilage cells with darkly stained round nuclei and also preformed fibres. The latter are invisible owing to the similarity of their refractive index to that of the ground-substance. Observe again, as in the case of the cornea, complete absence of blood vessels. Hyaluronidase or some closely related enzyme acting on the substrate of chondroitin sulphuric acid may regulate the metabolism of this avascular tissue. There is reason to believe that disturbance of this substrate-enzyme relationship may be the underlying cause of many rheumatoid disorders affecting the cartilage and capsule of joints. ($\times 262$)

The ability to increase tissue permeability or spreading activity is exhibited by certain types of pathogenic bacteria, particularly pneumococci and haemolytic streptococci, which secrete a spreading factor similar to hyaluronidase.

The permeability of the connective tissues will in part regulate the spread of infection, and control the degree of invading ability of pathogenic organisms. To this extent, therefore, it can determine susceptibility to infection. An animal with a high tissue-permeability should have a higher susceptibility to any infection to which the species is liable, and *vice versa*. For instance, experiment shows that young hosts, with their greater tissue-permeability, develop infection more severely than adults. This is, of course, only one factor in reaction to disease. Under experimental conditions, bacteria and viruses injected with a spreading-factor have an enhanced local primary effect. This is entirely quantitative, and does not promote new conditions or overcome a natural resistance.

Hyaluronic acid, and probably the other mucopolysaccharides, are non-antigenic. When injected into an animal they do not stimulate an immune reaction, i.e. they fail to arouse the normal defence mechanisms, including the production of antibodies, by which the body combats invasion by foreign material. Certain bacteria possess an external covering consisting of these non-antigenic mucopolysaccharides; this gives them a temporary protection from the cellular and chemical reactions of the host. During this period the organisms flourish and thrive, and thus the presence of this mucopolysaccharide capsule greatly increases their virulence.

Although the mucopolysaccharides are non-antigenic, the enzymes such as hyaluronidase are antigenic, and can produce antisera capable of suppressing the *in vivo* and *in vitro* activity of the enzyme. For example, if extracts of bull testes containing large quantities of hyaluronidase are

injected into a rabbit, serum can be withdrawn from the rabbit which will suppress the spreading power of the hyaluronidase extracts, and prevent the hydrolysis of hyaluronic acid. These antisera are specific for the source of their production. Some of the therapeutic effects of antisera in general may well be due, at least partly, to their anti-spreading properties. It is also possible that some types of sterility, previously attributed to sperm immunity, may be due to the formation of an antibody active against hyaluronidase. Some of these suspected cases have had their sera tested against bull testes hyaluronidase for increased inhibitory action, with negative results. Considering the species-specificity of hyaluronidase, this is of little significance, and the sera require to be studied against hyaluronidase from human testes.

Hyaluronidase has been used therapeutically to facilitate and hasten the absorption of fluid from the subcutaneous tissue. Normally, there is considerable tissue resistance, which limits the rate at which fluid can be injected. Preliminary injections of hyaluronidase are given to accelerate the absorption of physiological saline or plasma administered hypodermically, when intravenous injection is impossible. The effect of the hyaluronidase lasts for 24 hours.

An administration of 2.5 units of hyaluronidase makes possible the subcutaneous injection of contrast media for X-ray examination of soft parts, such as kidneys, where intravenous injection is contra-indicated or difficult, as it often is in children. There are many further possibilities for the therapeutic use of hyaluronidase.

There is a lack of information regarding the precise chemistry of the mucopolysaccharides, and more knowledge is needed regarding their biological properties. The protein-carbohydrate substances thus provide a wide field of research awaiting the activities of chemists, biochemists, and pathologists.

The chemistry of plant gums and mucilages

E. L. HIRST

The chemistry of gums and mucilages is extremely complicated, as they have high molecular weights and are composed of sugar residues of several different kinds. Their investigation is, however, rewarding, for it bears on one of the most fundamental problems in carbohydrate chemistry, namely the mechanism of the reactions by which the primary products of photosynthesis are transformed into different materials such as other hexoses and pentoses.

It has been known for many centuries that certain trees, in response to injury to their bark, exude nodules of gummy materials, which have long found a place in the arts and in industry by virtue of their capacity to form viscous pastes, thickening agents, and adhesives. The collection and distribution of these gums is an important branch of commerce, and some idea of the extent of the trade may be gained from the estimate that the yearly sales of gum from *Acacia* trees exceed 20 million kg. In addition, large quantities of gum tragacanth, obtained from *Astragalus* shrubs, of Indian gum from *Sterculia* trees, and of many other gums, are used in industry. These materials serve a wide variety of purposes, including sizing, the printing and finishing of textiles, paper-making, the preparation of water-colours, the manufacture of matches, inks, and pharmaceutical preparations, and in the confectionery trade. They exhibit a wide range of physical and chemical properties, and their scientific investigation has revealed many problems of importance to the biologist and to the chemist.

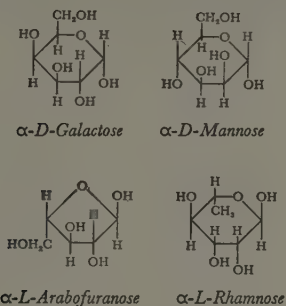
The mucilages are widely distributed in the plant world, being found as secondary membrane thickening, as intercellular material, and in the cell contents. They occur in the root, bark, cortex, leaves, stalks, flowers, endosperm, and seed coating, and in some bulbs special mucilage cells are present. Between them they play many parts in the life of the plant; they may function as food reserve materials, but in some instances they possess highly specialized functions. It is probable, for instance, that the physical properties of certain mucilages enable them to be used as water reservoirs by plants which live in exceptionally dry conditions, and mucilaginous seed-coatings may function similarly during germination.

The mucilages are normal products of meta-

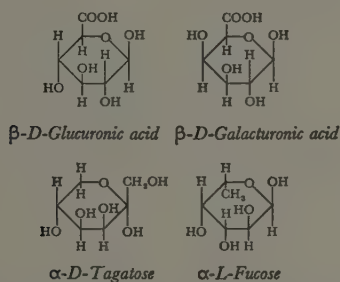
bolism, and in this respect they may be contrasted with the plant gums, which are usually formed in response to injury, either accidental, or deliberate as in the slitting of the bark of *Acacia* trees in order to encourage the outpouring of gum. The formation of gummy material under these conditions has been studied in detail, and it appears that starch and other reserve materials undergo transformation into gum, which then exudes as a mobile aqueous solution. This in turn dries to a hard solid, and so forms a protective layer over the injured part. It has been suggested that the gum is actually produced by invading bacteria, but the evidence for this is slight, and the results of recent chemical investigations are opposed to such a view. The plant gums are indeed so highly specific in their chemical structure that some workers believe that a knowledge of the chemical nature of any particular gum would enable the species and perhaps even the variety of the parent plant to be identified.

In their molecular structure, and in their capacity to give viscous solutions, the water-soluble gums closely resemble the plant mucilages, and it is convenient, therefore, to review the properties of both groups of substances despite the wide differences in their biological functions.

In respect of their chemical structures, the plant gums and mucilages are complex polysaccharides of high molecular weight, and in general they are built up by the union of sugar residues of several different kinds. For instance, the molecule of gum arabic contains *D*-galactose, *L*-rhamnose, *L*-arabinose, and *D*-glucuronic acid. Other sugar residues of frequent occurrence in gums and mucilages are *D*-xylose and *D*-mannose. On the whole, *D*-glucuronic acid is characteristic of the gums, while in the mucilages it is replaced by *D*-galacturonic acid, but this rule is not invariable.



Sometimes very rare sugars are encountered, as, for example, in the gum from the tree *Sterculia setigera*, which contains the ketose sugar *D*-tagatose, this being the only known instance of its occurrence in a natural product. The structures of many of the gums and mucilages are complicated still further by the presence of acetylated and methylated derivatives of the sugar residues. In illustration of this fact, mention may be made of the interesting mucilage obtainable from the bark of the slippery-elm tree (*Ulmus fulva*). Besides *D*-galactose, *D*-galacturonic acid, and *L*-rhamnose, this mucilage contains residues of 3-methyl-*D*-galactose.



The study of plant gums and mucilages leads us directly to some of the fundamental problems in carbohydrate chemistry, namely, the mechanisms by which the primary products of photosynthesis, which appear to be based on *D*-glucose, are transformed into other hexoses (e.g. *D*-galactose, *D*-mannose); uronic acids (*D*-glucuronic acid, *D*-galacturonic acid); methyl pentoses (*L*-rhamnose, *L*-fucose); and pentose sugars (*D*-xylose, *L*-arabinose, *D*-ribose). It is possible that a detailed structural examination of members of the group may throw light on these difficult questions, and some progress has indeed already been made. For instance, it is now certain that the transformation of *D*-galactose into *L*-arabinose does not take place in the polymeric molecules, despite the close stereochemical relationships of these sugars, and this is probably true also for the

TABLE I
Composition of some plant gums and mucilages

Substance	Sugar residues present
Gum arabic	Glu, G, R, A
Cherry gum	Glu, G, M, A, X
Damson gum	Glu, G, M, A, X
Egg plum gum	Glu, G, A, X
Mesquite gum	Glu, G, A and 4-methylglu
Gum tragacanth	Gal, G, F, A, X
<i>Sterculia setigera</i> gum	Gal, G, R, and D-tagatose
Linseed mucilage	Gal, G, R, X
Cress seed mucilage	Gal, G, R, X, A
Seed mucilages from <i>Plantago psyllium</i> and <i>P. fastigiata</i>	Gal, A, X
Seed mucilage from <i>Plantago arenaria</i>	Gal, G, A, X
Mucilage from bark of <i>Ulmus fulva</i>	Gal, G, R, and 3-methyl- <i>D</i> -galactose
Carrageen	G and sulphate
Fucoidin	F and sulphate
Agar-agar	G, L, and sulphate
Laminarin	<i>D</i> -glucose
Alginate	<i>D</i> -mannuronic acid

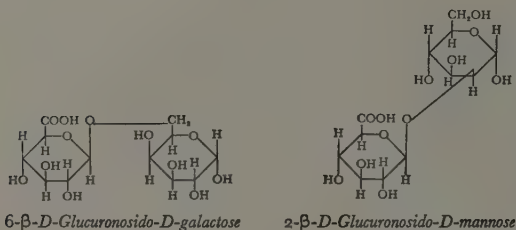
KEY

Glu = <i>D</i> -Glucuronic acid	F = <i>L</i> -Fucose
Gal = <i>D</i> -Galacturonic acid	A = <i>L</i> -Arabinofuranose
G = <i>D</i> -Galactopyranose	X = <i>D</i> -Xylopyranose
M = <i>D</i> -Mannopyranose	L = <i>L</i> -Galactose
R = <i>L</i> -Rhamnopyranose	

transformation of *D*-glucose into *D*-xylose [1]. It remains, however, to be ascertained whether the route favoured is direct enzymic transformation of the monomeric hexose molecules into the corresponding uronic acids and thence into the pentoses, or whether the hexose molecule is first broken down to trioses, as in alcoholic fermentation, with subsequent rebuilding.

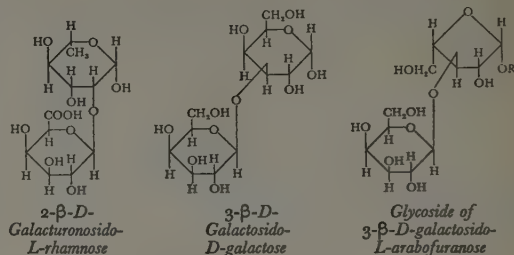
There are therefore many reasons for studying the structure of these complex substances, and there is the additional stimulus that they resemble structurally the bacterial polysaccharides which are so important in chemotherapy. The problems involved, however, are among the most difficult and complicated in the whole field of carbohydrate chemistry. In comparison, the study of cellulose and starch may be considered simple, since these polysaccharides, complex as they are, give rise on hydrolysis to one sugar only. On the other hand, the gums and mucilages usually contain several types of residue, and it is necessary to discover the order in which these occur in the molecule, the problems which arise being similar to those encountered in protein chemistry. Furthermore, a

hexose residue may be present in a gum as an α - or β -glycoside, in the pyranose or furanose ring form, and it may be combined through its hydroxyl groups with one, two, three, or four other residues. There are, therefore, scores of structural possibilities for each hexose residue, and the numbers for the pentose and uronic acid residues are almost equally formidable. Fortunately, certain regularities have been observed which introduce some simplification into the problem of assigning a place and structure to each residue, but it is not surprising that in no instance, up to the present, can a unique formula be assigned, although in many cases the broad structural features have been elucidated.

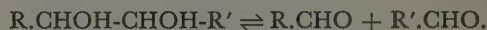


In the structural investigation of the gums and mucilages, after preliminary work to ensure the purity and homogeneity of the material under investigation, the polysaccharide is hydrolysed with acid in order to discover the nature of the constituent sugars and the relative proportions in which they are present. In this work, chromatography is proving to be a most valuable aid both for identification and for quantitative determination. Very fortunately, most gums contain groups of residues which are relatively resistant to hydrolysis, and the isolation and identification of these groups provides a first step in the piecing together of the molecular structure. For instance, the aldobiuronic acid 6- β -D-glucuronosido-D-galactose has been obtained from gum arabic. Damson gum and cherry gum, on the other hand, yield 2-D-glucuronosido-D-mannose, while the aldobiuronic acid from slippery-elm mucilage and from linseed mucilage is 2-D-galacturonosido-L-rhamnose. Sometimes disaccharides which resist hydrolysis can be isolated, and further important evidence concerning the linkages between residues is thus provided. Typical examples are 3-D-galactosido-D-galactose and 3-D-galactosido-L-arabinose, both of which are obtainable from gum arabic.

The arabinose residues are usually present in the labile furanose form and can be removed



readily by hydrolysis under mild conditions, leaving a 'degraded' gum which is still a high polymer but of simpler structure. The free hydroxyl groups in this product can be transformed into stable methyl ethers by standard processes, and the fully methylated polysaccharide gives on hydrolysis a complex mixture of partially methylated monoses which can be identified and estimated by chromatographic methods. The free hydroxyl groups in these sugars denote the points through which the various residues are linked together in the polymer, but experiments of this kind give no indication of the order in which they are arranged. Further information is gained by comparing these hydrolysis products with those obtained from the methylated derivative of the original undegraded gum, and this in turn is supplemented by evidence derived from the oxidation of the polysaccharides by per-iodic acid. This reagent attacks any sugar residue containing free hydroxyl groups on contiguous carbon atoms, but leaves untouched all those with linkages such that no glycol groupings are present:



With these items of information at his disposal it may then be possible for the chemist to formulate the main features of the molecular structure of the gum or mucilage with some precision, while the absolute size of the macromolecule may be investigated by physical methods such as osmotic pressure determinations, sedimentation in the ultracentrifuge, and light-scattering in solution. Should the molecule be long and regular in shape, as for example with alginic and pectic acids, X-ray analysis can give valuable information.

Gum arabic, on which much detailed work has been carried out, may be cited as an example of what has been achieved in structural determination in this group. It has been mentioned already that, by partial hydrolysis of the gum, an aldobiuronic acid and two disaccharides, all of known structure, can be isolated. Furthermore, methylation experiments have shown that the

degraded gum is built up of the following residues:

$G_1 \dots (1 \text{ mol.}); \dots 6G_1 \dots (5 \text{ mols});$

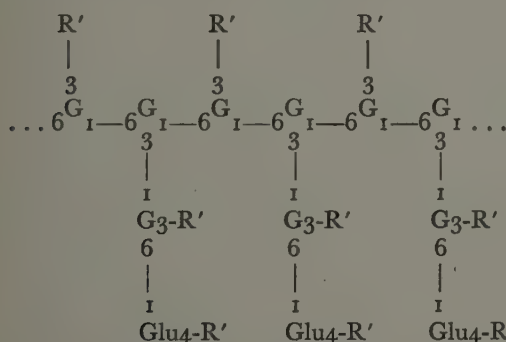
$\dots 6G_3^I \dots (3 \text{ mols}); \text{Glu } 1 \dots (3 \text{ mols}).$

($G_1 \dots$ indicates a *D*-galactopyranose linked through its first C atom; $6G_1$, a similar residue linked through C_1 and C_6 , and so on. Glu stands for a *D*-glucuronic acid residue.) In the original gum the residues present are:

$G_1 \dots; \dots 6G_3^I \dots; R_1 \dots; A_1 \dots;$

$A_3^I \dots; \text{Glu } 1 \dots; \text{Glu } 4 \dots$

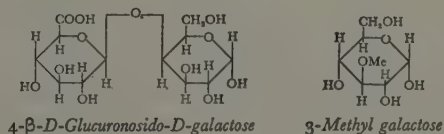
($R = L$ -rhamnopyranose residue, and $A = L$ -arabofuranose residue.) Building up from these data, F. Smith [2] was able to advance a possible formula for gum arabic. This, although not the only one which fits the evidence, shows the main features precisely, and the other possible variants differ only in detail.



One of the possible formulae for gum arabic. [$G = D$ -galactose residue; $\text{Glu} = D$ -glucuronic acid residue; $R' = L$ -rhamnose residue, or *L*-arabofuranose residue, or 3- β -*D*-galactosido-*L*-arabofuranose residue.

It will be seen that the structure consists of a continuous backbone of *D*-galactose residues, to which are attached numerous side chains containing other galactose residues together with the rhamnose, arabinose, and glucuronic acid residues. It is at present premature to generalize in this field, but there is some evidence that this backbone of galactose residues is of wide occurrence. It seems to be present also in damson gum [3], which is related to gum arabic in its general architecture but differs from it in containing *D*-xylose and *D*-mannose but no *L*-rhamnose. There

are, however, important structural differences, in that the aldobiuronic acid from damson gum, 2-*D*-glucuronosido-*D*-mannose, possesses a 1,2 linkage. Examination of the methylated gum has revealed the presence of at least ten different kinds of sugar residue, and, although the main feature again appears to be a chain of *D*-galactose residues, it is not surprising that no precise molecular structure can yet be put forward. Cherry gum [3] shows a close resemblance to damson gum but is even more complex. It gives rise to the same aldobiuronic acid, but as compared with damson gum it contains more *D*-xylose and *L*-arabinose residues. Rather unexpectedly, it appears that the gum from the egg-plum tree [4] is structurally more closely related to gum arabic, since the aldobiuronic acid derived from it is identical with the corresponding material from gum arabic. A preliminary examination of the gums from lemon and grape-fruit trees shows that in these yet another type of aldobiuronic acid is present, namely 4-*D*-glucuronosido-*D*-galactose, and the diversity of structure is further exemplified by mesquite (*Prosopis juliflora*) gum [5], which gives two such acids, 4- β -*D*-glucuronosido-*D*-galactose and a monomethyl ether of 6- β -*D*-glucuronosido-*D*-galactose.



The industrially important gum tragacanth is a mixture of a neutral polysaccharide, possibly an araban, and an acidic portion which resembles the mucilages in containing *D*-galacturonic acid residues in place of the glucuronic acid commonly found in gums. Methylation experiments [6] have revealed the general structure, which is built up of residues of:

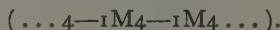
$F_1 \dots; X_1 \dots; X_2^I \dots; \text{Gal } 4 \dots;$

together with some triply bound galacturonic residues. ($F = L$ -fucose, $X = D$ -xylose, $\text{Gal} = D$ -galacturonic acid.)

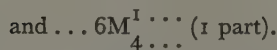
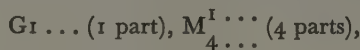
The plant mucilages possess molecular structures of the same general type. For convenience, they may be classified into three main groups: (a) neutral polysaccharides of high molecular weight containing one or more kinds of sugar residues, but no uronic acid; (b) acidic polysaccharides resembling the gums but usually with

D-galacturonic acid as the acidic residue; and (c) polysaccharides, frequently present in algae, of complex structure and high molecular weight, containing sulphate ester groupings.

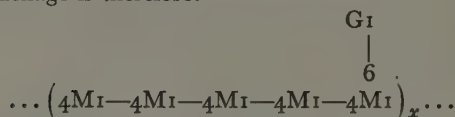
Large numbers of these have been isolated, and they are clearly of great biological interest and importance, but comparatively little is yet known of the detailed structure of any of them. In this article, it will be possible only to mention briefly one or two typical examples. One of the simplest is the salep mannan obtained from the tubers of one of the *Orchidaceae*. This appears to be a linear polymer of 1,4-linked mannopyranose residues:



Gum gatto [7] (carob seed mucilage, probably very similar to locust bean mucilage) is more complex, being composed of the following residues:



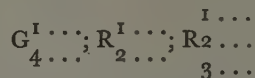
One of the possible molecular structures for this mucilage is therefore:



Lucerne seed mucilage also consists of *D*-galactose and *D*-mannose residues, but its structure is more complicated, since two types of galactose residue are present, and the mucilage differs from gum gatto in that no 1,4-linked mannose residues are present. In many other of the neutral mucilages *L*-arabinose occurs in large proportions, together with *D*-galactose.

Still greater complexity is encountered with the mucilages of class (b), some of which have been examined in considerable detail. Examples of great interest are to be found in the seed mucilages of various species of *Plantago*. These all contain *D*-galacturonic acid residues, but display remarkable differences in detailed structure from species to species. The mucilage from *P. arenaria* contains *D*-xylose, *D*-galactose, and *L*-arabinose; that from *P. lanceolata*, *D*-galactose, *L*-rhamnose, and *D*-xylose; and those from *P. psyllium* and *P. fastigiata* *L*-arabinose and *D*-galactose. Methylation experiments conducted with the mucilages from *P. lanceolata* and *P. arenaria* have revealed a bewildering complexity of structure, with the xylose residues acting as branching points in a highly ramified molecule [8].

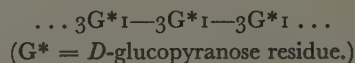
Some mucilages in this group, for instance those from quince seed and white-mustard seed, occur in the plant in combination with cellulose, the complex being water-soluble. Linseed mucilage yields on partial hydrolysis the aldobiuronic acid 2-*D*-galacturonosido-*L*-rhamnose, which occurs also in the gum from *Sterculia setigera* and in the mucilage from the bark of *Ulmus fulva*. *Ulmus fulva* mucilage has been studied by the methylation method, and it is known that residues of



are present in addition to residues of 3-methyl galactose, but no detailed structure can yet be assigned [9].

Problems of special difficulty abound in the study of the algal mucilages, which contain sulphate ester groupings. The best known of these mucilages contain sulphated galactose residues (agar-agar from *Gelidium* and *Gracilara* spp.; carrageen from *Chondrus crispus*), or sulphated fucose residues (e.g. fucoidin from *Laminaria* and *Fucus* spp.). There is reason to suppose that in carrageen the sulphuric acid residue is linked to C₄ of a galactose residue, and that the essential feature of the molecular structure is a backbone of 1,3-linked *D*-galactose residues, similar to that found in the plant gums [10]. The mucilage from the seaweed *Gigartina stellata* probably contains a similar galactose backbone, with attached side chains [11]. Agar-agar is known to contain 1,3-linked *D*-galactose residues, but on hydrolysis this substance gives rise also to *L*-galactose, and from fully methylated agar-agar it is possible to obtain derivatives of 3:6-anhydro-*L*-galactose. The structure is highly complicated, and despite intensive work no structural formula can yet be advanced with certainty [12].

As a final example we select the interesting and unusual mucilage laminarin [13], which occurs in *Laminaria* spp. together with alginic acid and mannitol. It consists solely of *D*-glucose residues, some of them possibly sulphated, and it is of interest to note that here again we encounter the 1,3-linkages which are so frequently present in algal polysaccharides. The main features of the structure are represented by the formula:



It is remarkable that the property of gumminess should be shared by so many substances of diverse chemical structure, and at present only a partial explanation of this can be given. It is probable that if a water-soluble substance is to be capable of acting in this way its molecule must contain hydroxyl groups capable of forming hydrogen bonds with water molecules, while at the same time the geometry of the molecules must be such that these cannot readily align themselves closely and regularly with each other. When this can happen, as in the case of the unbranched thread-like molecules of cellulose, intermolecular hydrogen bonding results in the formation of insoluble material which can be dispersed only by a solvent having a still stronger affinity for the hydroxyl groups. It is known, however, that a disturbance of the geometrical arrangement in cellulose, occasioned by the introduction of a small percentage of

bulky substituent groups, will result in the formation of water-soluble derivatives. We have seen that most of the gums and mucilages possess highly branched structures, the hydroxyl groups in which are ideally placed for attachment to water molecules, and even in the simpler cases there is no possibility of that compact geometrical alignment with intermolecular hydrogen bonding such as occurs in cellulose. In consequence, the gums remain heavily hydrated even in the most concentrated solutions. Nevertheless, there must be some intermolecular hydrogen bonding between the gum molecules themselves—not very pronounced in highly dilute solution, but tending to give a structure of increasing rigidity as the water is removed—and it is possible that an explanation of the characteristic physical properties of the gums and mucilages is to be found in the delicate interplay between these two opposed reactions.

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Book reviews

SCIENCE AND LIFE

Man is a Microcosm, by J. A. V. Butler. Pp. 151, with line and half-tone illustrations. Macmillan and Company Limited, London. 1950. 10s. 6d. net.

Dr Butler has written an admirably clear, balanced, and up-to-date account of the modern application of physics and chemistry to the life of organisms and man, and its implications for our view of man. Beginning with the chemistry of proteins, he proceeds to discuss enzymes, vitamins, hormones,

viruses, and genes, and outlines their roles in the maintenance and control of the living organism, in development and growth, in reproduction, and in the action of muscles, nerves, and brain. He reviews our meagre knowledge of the origin of life, throws much light on the fashionable analogy between the brain and a calculating machine, and concludes with a chapter on the stature of man.

Dr Butler's aim is to suggest some notion of the great complexity and

ingenuity exhibited in the working of living things as they are now understood, in order to correct the view derived (illogically) from nineteenth-century physics, that man is an insignificant being because he lives on a planet which is not astronomically important, still less unique, and is a mere speck in the immensity of space. Dr Butler suggests that 'the balance may be redressed by the complementary studies of living structures, which, by revealing a world as rich in texture as

the other is vast, may make men feel again that they are not out of keeping with the splendour of their setting.' This is a most stimulating and honest book, and will be useful both to the scientist and to the general reader.

E. F. CALDIN

A CENTURY OF TECHNOLOGY

A Century of Technology, edited by Percy Dunsheath. Pp. 346, with twenty illustrations and five line diagrams. Hutchinson's Scientific and Technical Publications, London. 1951. 15s. net.

In the last hundred years, science has made a greater impact on civilization than during any previous century. Not only have investigation and research been very much more active; in addition, we have learned to make vastly greater practical use of the discoveries we have made. To describe technological progress since 1851 is a Herculean task. In *A Century of Technology* this has been attempted by eighteen specialist contributors under the editorship of Dr Percy Dunsheath. The result is a book which, in providing a bird's-eye view of this exciting century of science, must prove invaluable to all scientists and technicians.

It is unavoidable that in a survey of this sort many things should be omitted or given but scant attention. The development of radio, for example, and the lively new field of synthetic fibres, are two subjects which deserve to be treated more fully than they are. Such criticisms are, however, inevitable in discussing a survey of this type. A quart can never be persuaded into a pint pot without something being spilled.

J. G. COOK

PHYSICAL ORGANIC CHEMISTRY

Physical Aspects of Organic Chemistry (fourth edition), by W. A. Waters. Pp. xii + 539. Routledge and Kegan Paul, London. 1950. 35s. net.

Since it first appeared some fifteen years ago this book has been recognized as one of the best surveys of the theory of organic chemistry. The intervening years have seen great changes, and the basic ideas of chemical theory have been placed upon a wider and firmer foundation. The newer quantum theories, the concept of resonance, the unravelling of the intricacies of molecular structure, and many other developments have resulted in the emergence of a clearer picture of the fundamental mechanism of chemical change. It is in terms of these new ideas that the

principles of organic reactions should be formulated. The fusion of the different concepts of the physical and organic chemist is difficult, since they look at reactions from a different viewpoint. In the present edition, which has been largely rewritten, Dr Waters has successfully achieved this end, and has given a unified and comprehensive summary of a very wide subject. His viewpoint is essentially that of the organic chemist, and he develops his treatment from the historical aspect. The old and newer ideas are given equal prominence, and the difficulties of terminology which have arisen with the growth of the subject, and which have led to much confusion, are clearly and concisely explained. The basic principles of modern theoretical organic chemistry are formulated, and applied to the many types of organic reactions. These ideas are developed in chapters which cover free radical reactions, catalysis, ionization and ionic reactions, strength of acids, ester hydrolysis and esterification, substitution reactions, molecular rearrangements, ionotropic change, and reaction of conjugated systems, with two final chapters on aromatic behaviour. The volume serves the dual purpose of an up-to-date review and an advanced textbook, and should be valuable to both the student and advanced worker.

C. E. H. BAWN

PRACTICAL SPECTROSCOPY

Practical Spectroscopy, by G. R. Harrison, R. C. Lord, and J. R. Loofbourow. Pp. xiv + 605, with numerous half-tone and line diagrams. Blackie and Son Limited, London. 1949. 35s. net.

The 600 pages of this book give a comprehensive account of almost every aspect of modern practical spectroscopy. Among the many subjects dealt with are spectrograph types and mountings; conditions of illumination; characteristics of various sources; technique of photography; principles of quantitative intensity; measurements by photographic, photoelectric, and bolometric means; absorption spectroscopy; spectroscopy of the infra-red and vacuum ultra-violet; Raman effect; and interferometry. There are chapters on qualitative and quantitative spectrochemical analysis, and on the theory of atomic and molecular spectra. The book is extremely clearly and well written, so well indeed that it makes the subject look perhaps a little too easy, and as though there are few problems

left to solve. In the sections on visible and ultra-violet emission spectra the emphasis is on atomic spectra, and the existence of molecular emission spectra is largely ignored. The section on discharge tubes and sources for band emission spectra is relatively weak, and a description of modern low-voltage hydrogen lamps would be welcome. However, these are details, and the treatment is so full that it is easier to list what it omits than what it includes. This most valuable, indeed indispensable, work originates from the Massachusetts Institute of Technology, which has done so much to develop spectroscopy, and the combination of a physicist, a chemist, and a biophysicist has produced a balanced, and yet smooth, account of the whole subject.

A. G. GAYDON

BORON TRIFLUORIDE

Boron Trifluoride and its Derivatives, by H. S. Booth and D. R. Martin. Pp. 315, with several line diagrams. John Wiley and Sons, New York; Chapman and Hall Limited, London. 1949. 40s. net.

The usefulness of boron trifluoride in organic chemistry as a catalyst for alkylation, polymerization, and isomerization reactions has brought this compound very much into the fore in recent years. It has, indeed, been produced commercially since 1936, and has a well-established place both in research and in industry. The authors of this monograph have collected and classified the information on boron trifluoride and its derivatives which has accumulated since the compound was discovered in the early part of the last century. They deal in turn with its preparation and physical and chemical properties, the co-ordination compounds, the fluoboric acids and their salts, and the catalytic properties. The two final chapters are on the analysis of boron trifluoride and its derivatives, and on its practical handling. The bibliography contains almost a thousand references, among which are many from the patent literature.

The most useful section of the book is that on catalysis by boron trifluoride and its derivatives. The information given is systematically arranged, and enables the reader to follow the literature on a particular topic with great ease. The incompleteness of our understanding of the structure and mode of action of the organic derivatives is all too clear. Unfortunately, the authors give little assistance in this

respect. For the most part their approach is non-critical, and they are often contented to state the bare facts much as they would be recorded in *Chemical Abstracts*. They also fail to come to grips with the very difficult problems of nomenclature which are raised. In spite of these limitations, however, their work can hardly fail to create interest in the subject. Not only in the organic, but also in the inorganic and physicochemical fields, there are many problems which await further study and elucidation. So complete a review of the present position will stimulate further progress.

H. J. EMELÉUS

ELEMENTARY CHEMISTRY

College Chemistry, by *Linus Pauling*. Pp. 705, with two coloured plates and many other illustrations. W. H. Freeman and Company, San Francisco, California. 1950. 34s. net.

This is a delightful book, designed to lead a complete beginner step by step logically to a sound understanding of the fundamentals of general chemistry. The approach to the subject is the modern one, and follows much the same lines as the author's *General Chemistry* but proceeds at a rather gentler pace. The nature of atoms and the molecular structure of matter are introduced early, and descriptive chemistry is introduced gradually against this background and alongside a discussion of theoretical principles. The selection and presentation of subject-matter, which ranges over a very wide field, make reading and assimilation easy; in fact, the text really teaches the subject-matter. Each chapter concludes with a summary of the concepts, facts, and terms which have been introduced, followed by the usual exercises and questions.

The book is well printed and plentifully illustrated with attractive diagrams and perspective drawings. It is broader in its concept, and in places less detailed, than demanded by some English examinations, but even in this connection it can be recommended to students reading for the General Certificate (Advanced and Scholarship papers) and for the Intermediate B.Sc. It gives an unusually clear picture of the subject as a whole as well as illuminating explanations of some theoretical topics; even quite advanced students will find in it much that is of advantage.

F. FAIRBROTHER

RADIATIVE TRANSFER

Radiative Transfer, by *S. Chandrasekhar*. Pp. xiv + 393, with several line diagrams. Clarendon Press, Oxford. 1950. 35s. net.

A typical problem in radiative transfer is to calculate the properties of the diffusely reflected and transmitted radiation if radiation is incident in a given direction on a layer of scattering material. In each elementary scattering process the amount of radiation scattered from one direction to another may vary with the angle between these directions, and with the state of polarization of the radiation. The results may be obtained as the solution of (a) integro-differential equations of transfer, or (b) integral equations which are the mathematical expression of principles of invariance, arrived at by regarding any single layer of material as equivalent to two adjacent layers.

Professor Chandrasekhar is a leading contributor to the mathematical formulation of such problems, and to the origination and development of methods of solution. The latter include his exploitation of 'Gauss sums' to replace integrals, and his investigation of a new class of non-linear integral equations. This book is largely an account of his own recent work, illustrated by applications to problems of the sunlit sky and of planetary and stellar atmospheres. Its importance for problems of neutron-diffusion is mentioned but not illustrated. The author aims at a unified treatment, possessing a sufficient degree of accuracy, of a comprehensive class of problems. His book revolutionizes the outlook upon a great part of the subject and marks an epoch in its development.

W. H. MCCREA

THE ACTINOMYCETES

The Actinomycetes, by *Selman A. Waksman*. Pp. xviii + 230, with 36 half-tones and 9 line drawings. Chronica Botanica Limited, Waltham, Mass. 1950. \$5 net.

When Dr Waksman isolated the series of antibiotics exemplified by streptomycin he brought the actinomycetes at one bound out of obscurity into prominence. Today the culture of these micro-organisms is an industry, and a knowledge of their morphology, classification, and nutritional requirements has become of far more than academic importance. In this book, however, Dr Waksman lays no undue stress on antibiotic production, which receives a brief but masterly survey in the 26 pages of Chapter 7. The pre-

ceding chapters give a balanced review of the taxonomy, morphology, and metabolism of the group, and a more detailed account of seven selected species. A further 40 pages sum up the literature on the distribution and function of the actinomycetes in nature, and on the part they play in inducing plant and animal diseases.

The production has occasional irritations for the reader, such as the unnecessarily small type for the table headings, and the use of an eye-tiring glossy paper not justified by the quality of the photographs printed with the text. These are, however, minor flaws in a volume which on every page shows evidence of having been written by an outstanding participant in the study of the actinomycetes.

R. W. MARSH

DETECTION OF ATOMIC PARTICLES

Ionization Chambers and Counters, by *D. H. Wilkinson*. Pp. 266, with various line diagrams. Cambridge University Press, London. 1950. 25s. net.

Dr Wilkinson's book is another notable addition to the already long list of Cambridge monographs. It is a book for the specialist but one which every nuclear physicist should possess, covering as it does a field on which so much has been written in research periodicals but to which so few books have been devoted.

The first four chapters give a lucid description of the fundamental theory involved in the use of ionization chambers, proportional counters, and Geiger counters. The next three chapters deal with the more practical aspects of each of these devices individually, and the last chapter very briefly describes the statistics of the recording and counting of charged particles. In general, the main emphasis is on proportional and Geiger counters, and an excellent review of the present state of the theory of their modes of action is given, as well as many practical tips for their operation.

The style of writing is clear, if at times a little robust. In addition, the reviewer hopes that, when the second edition appears, the excellent and most useful final chapter may perhaps be somewhat lengthened. The list of references is comprehensive, and drawn from an unusually wide field.

This volume is rather more expensive than its companions in the series, but it should nevertheless have a wide sale.

C. L. SMITH

Notes on contributors

P. W. BRIDGMAN,

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Was born in 1882 and was educated at Harvard University. He has been a member of the physics department in that university since 1908 and Hollis professor of physics since 1926. His principal experimental work has been the measurement of various physical effects of high hydrostatic pressures. He has also written on thermodynamics and the foundations of physics. He was awarded the Nobel Prize for physics in 1946.

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Has been Sherardian professor of botany in the University of Oxford since 1937. Was born in 1887 and was educated at Burnley Grammar School and the University of Manchester. From 1908 to 1912 he was lecturer in economic botany at the University of Manchester. In 1912 he became professor of botany at the University of Adelaide and consulting botanist to the South Australian Government. From 1928 to 1937 he was professor of botany in the University of Sydney. As Sherardian professor he has the charge and supervision of the Botanic Garden and has been an *ex officio* curator since 1943.

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Was born in Parrsboro, Nova Scotia, in 1904. After graduation from Dalhousie University he was awarded an I.O.D.E. overseas scholarship and went to work at the University of Liverpool. Later, as a Fellow of the Rockefeller Foundation, he worked at the Biological Station at Heligoland and the University of Kiel. His publications have been mainly in the field of chemical embryology, and, more recently, limnology. He is professor of zoology in Dalhousie University, Halifax, N.S.

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Was born in 1897 and was educated at Sherborne School and Lincoln College, Oxford. For some years from 1921 he was a schoolmaster, but soon became known to a wide circle of the general public as a successful expositor of science. Though he acknowledges that his purpose in life is 'to know a little about as many subjects as possible,' he is deeply versed in the history of science, particularly Greek alchemy, and has been editor of *Ambix* from 1937. In 1940 he became acting curator of the Museum of the History of Science at Oxford, and in 1950 he was appointed Director of the Science Museum, South Kensington.

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Was born in 1907 and graduated in physics at Bristol University in 1927. For two years he carried out physical research at the H. H. Wills Physical Laboratory at Bristol and then (1929-32) became resident observer at Kew observatory. From 1932 to 1933 he was Government meteorologist, and then reader in meteorology in the University of London. In 1950 he was appointed hon. secretary and editor of the Royal Meteorological Society. His main interest is in atmospheric turbulence.

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Is professor of plant physiology in the University of Madrid. He was born in Liverpool in 1902. Since 1947 he has been investigating the antibacterial products of lichens. He has published several books on antibiotics, including

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Born in Glasgow in 1903, and educated at Glasgow High School and Glasgow University. Joined staff of Anatomy Department, Glasgow University, in 1930, and became senior lecturer in 1937. Recently appointed Regius professor of anatomy in Glasgow University. Has published work on embryological problems and reproductive endocrinology. During the last war was engaged on work concerned with the problems of nerve grafting.

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Born in Szeged (Hungary) in 1905; is now a naturalized British subject. Was educated at Szeged University. In 1934 began research work in London at King's College and University College. In 1936 he was appointed lecturer in anatomy at Birmingham University; in 1937 became senior lecturer in histology and embryology at Glasgow University. Has published work on histological endocrinological aspects of reproductive physiology. Was engaged during the war on problems of nerve grafting.

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Was born at Preston in 1898; he is now professor of organic chemistry in the University of Edinburgh. Educated at Northgate School, Ipswich, Madras College, St Andrews, and the University of St Andrews. Has held teaching posts in the Universities of St Andrews, Durham (Armstrong College, Newcastle-upon-Tyne), Birmingham (lecturer 1927, reader 1934), Bristol (professor of organic chemistry 1936), Manchester (professor and director of chemical laboratories 1945). His scientific work has been concerned mainly with the chemistry of the carbohydrates, including vitamin C, with special attention in recent years to the starches, hemicelluloses, and plant gums. He was awarded the Davy Medal of the Royal Society in 1948.

ENDEAVOUR

The British quarterly scientific review ENDEAVOUR was first published in January 1942. Its purpose was to enable men of science, and particularly British men of science, to speak to the world in an hour when not only nations but the internationalism of science suffered the dangers of warfare. For the better fulfilment of this purpose ENDEAVOUR was from the first published in four separate editions—English, French, Spanish, and German. An Italian edition has been published since January 1948. Today the situation is happily different, but there can be no lasting peace without full and sincere co-operation between nations in every realm of human enterprise. In the scientific field ENDEAVOUR can thus play as useful a part in peace as it did in war, and for this reason the decision has been taken to make its publication permanent.

ENDEAVOUR is distributed without charge to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

